PRICE TEN SHILLINGS AND SIXPENCE

THE JOURNAL OF The Institution of Electrical Engineers

ORIGINALLY

The Society of Telegraph Engineers

FOUNDED 1871

INCORPORATED BY ROYAL CHARTER 1921

EDITED BY P. F. ROWELL, SECRETARY

SAVOY PLACE, VICTORIA EMBANKMENT, LONDON, W.C.2

Telegrams: "VOLTAMPERE, PHONE, LONDON." Telephone: TEMPLE BAR 7676.

Vol. 83 DECEMBER, 1938 No. 504

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E. and F. N. SPON LIMITED, 57 HAYMARKET, LONDON, S.W.1.
CHEMICAL PUBLISHING COMPANY OF N.Y. INC., 148 LAFAYETTE STREET, NEW YORK.

The Institution of Electrical Engineers.

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THE LONDON TELEVISION SERVICE

By T. C. MACNAMARA and D. C. BIRKINSHAW, M.A.

(*Paper first received* 1st *December*, 1937, *and in final form* 26*th February*, 1938; *read before* THE INSTITUTION 21*st April, and before the* NORTH-EASTERN CENTRE 11*th April*, 1938.)

SUMMARY

This paper describes a television broadcasting station recently built by the British Broadcasting Corporation in a part of the Alexandra Palace, London, N. The development of the television service in this country is traced from the early attempts to promote an experimental service of transmissions on low standards of definition to the establishment of a high-definition public service.

The paper is divided into six parts.

Part 1 touches briefly upon the history of television development in this country, and describes in some detail the transmission of low-definition pictures from B.B.C. stations during the years 1929 to 1935.

Part 2 deals with the recommendation of the Television Committee that a station for transmitting high-definition television should be established, and it discusses various factors upon which the subsequently appointed Television Advisory Committee based its decisions regarding the choice of the Alexandra Palace site, the operating wavelengths, and standards of definition.

Part 3 describes the arrangement of studios and apparatus rooms at the Alexandra Palace station. The problems of studio acoustics, production lighting, and the provision of essential supplies, are also dealt with.

Part 4 describes the layout and arrangement of the control room and transmitter equipment installed for the vision and accompanying sound transmissions.

Part 5 is concerned with the plant developed to enable current events and other programme items taking place at some distance from the Alexandra Palace to be televised. Some account is given of the use of land lines to carry television signals.

Part 6 is a brief consideration of the reception results of signals from the Alexandra Palace since the beginning of the service, and embodies the result of signal-strength surveys made in the vicinity of, and at distances from, the station.

Finally, the various types of television receivers and aerials are discussed.

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INTRODUCTION

This paper gives a general description of the London Television Station and touches upon past experience with experimental 30-line transmissions. It discusses the circumstances influencing the Television Advisory Committee's recommendations regarding the establishment of a high-definition service, and the subsequent factors governing the choice of operating wavelengths, standards of definition, and the Alexandra Palace site.

Following upon the recommendations of the Television Advisory Committee, the British Broadcasting Corporation has acquired on lease a portion of the Alexandra Palace premises in North London which, with slight modifications, were arranged to accommodate two complete television systems of the Marconi-E.M.I. and Baird companies respectively, each system having its own studio premises and vision radio-transmitter. A third radio transmitter is provided to broadcast at will the sound accompanying the vision of either system. Two aerial systems are provided, the one interchangeable

between the two vision transmitters, and the other permanently connected to the sound transmitter.

In addition to the premises set apart for present technical requirements, the British Broadcasting Corporation has also leased the Alexandra Palace Theatre, which it is anticipated will provide additional studio accommodation in due course. Certain other areas have been converted into offices for the technical and production staffs.

In the course of the paper the arrangement of the areas referred to above is described and illustrated by means of plans, followed by descriptions of the apparatus installed. The acoustic treatment of the studios and the arrangement of production lighting are described, together with a reference to conditions of working during the production of studio scenes.

An account is given of the equipment developed for television outside broadcasts and of the problems associated with the transmission of television signals over land lines.

The final part of the paper gives an account of the general performance of the station, in so far as this has been ascertained since the inception of the service.

PART 1

EARLY TELEVISION AND THE 30-LINE EXPERIMENTAL SERVICE

(a) Brief Historical Survey of Early Television Activities

Although usually considered to be a modern art which has made accelerated progress in recent years, television has its beginnings deeply rooted in the past. In the case of other similar achievements it is often found that early scientific discoveries have been made for which no immediate practical use could be found, but television differs in that, long before it was contemplated, an accidental scientific discovery clearly indicated the possibility of seeing at a distance.

In 1817 the metal selenium was discovered by Berzelios, and 56 years later an operator named May, working at the terminal of the Atlantic cable at Valencia on the south-west coast of Ireland, discovered that the behaviour of some selenium resistances in use at the station varied according to the amount of light shining upon them through the window. It was, of course, realized that, just as the transmission of sound to a distance by cable necessitates the creation of an electric current which faithfully represents it, so, in order to see at a distance, we must have some means of controlling a current by means of light; and this discovery by May, quickly confirmed by W. Smith and W. G. Adams, created immense interest and may be said to have been the true beginnings of television.

It was clear that television, in common with other methods of transmitting a picture to a distance such as phototelegraphy, required a solution to the problem that the communication channel can be said to have only two dimensions whereas the picture to be transmitted has three. Consequently some means of reducing the three dimensions of the picture to two only were required before television in a practical form could be realized. This was, and still is, accomplished by splitting up the picture into elements which are transmitted successively, and in 1884 the Polish scientist Nipkow invented his famous disc, which is still in use in certain systems of television to-day. Meanwhile other discoveries destined to contribute to the success of television were being made. Faraday in 1845, and Kerr in 1877, had demonstrated the effect of magnetic and electrostatic fields on polarized light. It was not, however, possible to achieve television, as no means of amplifying the very small currents available had yet been found, and therefore a special interest attaches to a description by A. A. Campbell Swinton in *Nature* in 1908 of a device which was the forerunner of the "Emitron" used to-day at the London Television Station. This apparatus fundamentally possesses a comparatively high sensitivity, owing to an inherent electrical storage effect.

During the years 1923 to 1928, experiments carried out by J. L. Baird finally resulted in the completion of a television system which gave tolerably faithful reproduction of an object transmitted through the medium of a line connection between transmitter and receiver.

It was realized that the range of frequencies necessary for the elementary degree of definition then used was only a little greater than was required for the faithful transmission of sound, and it was considered that it might be possible to transmit such pictures over the normal sound-broadcasting system.

(b) The First Regular Transmissions of Television of Low Definition

In 1929, arrangements were made between the British Broadcasting Corporation and Baird Television, Ltd., for the regular broadcasting of television from the B.B.C.'s London station, which was then a 2-kW transmitter situated in Oxford Street. In the system then in use the transformation of the picture into a succession of elements, or "scanning," was accomplished by dividing the picture into 30 vertical strips, or lines, each line being explored in succession by a square aperture, whose width and height were each equal to the width of one line. The number of pictures transmitted per second was 12½, this being achieved by repeating the scanning cyclicly at this frequency. These transmissions, which were unaccompanied by sound, lasted for ½ hour and took place daily except on Saturdays and Sundays, the studio being situated at the laboratories of the Baird Co. in Long Acre.

In October, 1929, these transmissions were transferred to the B.B.C.'s station at Brookman's Park. As this station is equipped with two separate transmitters, one for the National and one for the London Regional programme, it became possible to transmit the sound associated with the television programme, and this was started on the 14th April, 1930.

(c) The Equipment of a Television Studio at Broadcasting House

The British Broadcasting Corporation watched very closely the results of these early experimental transmissions and the progress which was being made at the same time in the laboratories of the Baird Co., and it was decided in 1932 to equip one of the studios in the basement at Broadcasting House with the latest 30-line television apparatus designed by the Baird Co., and to take

over the responsibility for originating the transmissions, as by this means more direct experience would be gained of the problems entailed in the production of suitable television programmes.

A studio was therefore set apart in the sub-basement of Broadcasting House, with a small adjoining room having an intercommunicating window between it and the studio. The television scanning apparatus was installed in the adjoining room and operated through the window.

The installation of the apparatus was commenced in July, 1932, and the first programme was transmitted on the 22nd August. The vision signals were still radiated from London National, but the sound signals were radiated from Midland Regional instead of London Regional from this date.

Fig. 1 shows the layout of the control-room apparatus, from which the various parts of the equipment can be located as described.

The apparatus comprised the following sections:—

(1) The scanning-beam projector for generating the spot of light which is required for the spotlight system.
(2) The photocells.
(3) The amplifiers and mixers.
(4) The caption scanner.
(5) The sound apparatus.

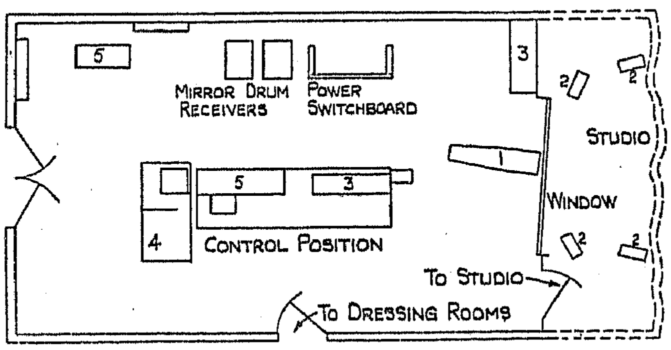

Fig. 1

follow the corresponding movements in the studio. Forward and backward movements were followed, as has been explained, by the arc adjustment. The drum was driven by a synchronous motor situated inside it and running at 750 r.p.m. from 50-cycle a.c. mains at 110 volts.

At the end of each line it was necessary to transmit a synchronizing signal, taking the form of a pulse of absolute black which was generated by a mask on the mirror drum which allowed a specific interval at the end of each line. In this interval the photocells received no light, and an electrical black pulse was generated.

(2) The studio was equipped with nine large gas-filled caesium photo-electric cells, and two further banks of four smaller cells per bank. This number of photocells was greatly in excess of that required purely for reasons of sensitivity, but since the photocells must be regarded as light sources from the point of view of illumination of the picture, it was necessary to fit a number to obtain lighting of some artistic merit.

(3) The photocells were connected together to form four groups, and each of these outputs was then applied to its own "A" amplifier, and the outputs of each of these amplifiers were led to a desk, at which an engineer could mix them in desired proportions. It is interesting to note that the operation of these mixing controls had, of course, the effect of varying the intensity and apparent direction of the lighting of the scene.

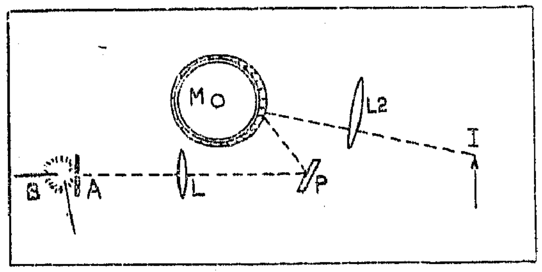

Fig. 2

(1) A schematic drawing of the optical system of the projector is shown in Fig. 2. An arc lamp at B, having its positive carbon horizontal, irradiated an aperture A situated about $\frac{1}{2}$ in. from the positive crater and consisting of a hole 0·125 in. square in a plate of metal.

The light passed to the convex lens L, having a focal length of 22 in., which focused an image of the illuminated square aperture on the artist, via the optical path AL, LP, PM, and MI. P was a plane mirror which reflected the beam on to the mirror drum situated at M. The drum consisted of a metal cylinder having 30 milled surfaces to which were fixed mirrors radially spaced evenly round the drum.

In order to bring the spot into focus on the artist the arc lamp could be moved towards or away from the lens by means of a hand-wheel. The scanning of a very close-up view could not be accomplished by this, however, and when such a view was wanted, the scanned area was reduced in size by an auxiliary long-focus convex lens which could be swung into the optical path in front of the drum, and which is shown at L2.

The projector could be swung horizontally about a fulcrum to follow sideways movements of an artist, and a mask could be raised or lowered to vary the sector of light taken from the drum upwards and downwards to

After passing through the main volume control the signals were further amplified in a "B" amplifier, and thence passed to a pair of "C" amplifiers. One of the "C" amplifiers fed the signals to the main control room at Broadcasting House, from which they were passed by land line to the London National transmitter. The other "C" amplifier supplied a local picture monitor.

(4) In order to be able to transmit titles, tuning signals, and other matter which could conveniently be drawn on a small card, an additional scanner was provided. In this apparatus a spotlight method was again used, light from a 900-watt lamp being distributed by a Nipkow disc on to the card, which was viewed by two photocells. The card was held in place on one of the sides of a dodecahedron made of wood, so that 12 cards could be prepared and brought into position one by one. This subsidiary apparatus had its own individual amplifiers and mixers.

(5) The sound part of the transmissions was picked up by three microphones. The outputs of these were led to mixers, followed by "A" amplifiers. The signals were then sent to the Broadcasting House Control room, from which they were connected by line to the Midland Regional transmitter at Daventry.

Programmes were given four times a week for $\frac{1}{2}$ hour from the above studio, and transmissions included items

of varied type, such as variety, ballet, exhibitions of pottery and pictures, and animals from the Zoo.

At the beginning of 1934, as the development of studio technique progressed, it was realized that it would be desirable to have the use of a larger studio. A new studio was accordingly prepared at 16, Portland Place, which adjoined Broadcasting House and was the property of the B.B.C., and on the 16th February, 1934, the transmissions were suspended for 10 days so that the television apparatus could be moved over to the new studio. The programmes were recommenced on the 26th February.

(d) The Cessation of the Experimental Service

Meanwhile, improved systems of television having greater definition and less flicker were being developed, and it was evident that the time was not far distant when the 30-line transmissions would be discontinued. As a preliminary to their discontinuance, the number of transmissions per week (then four) was reduced as from the 31st March, 1934, to two, the length of each transmission, as before, being ½ hour. After a time, however, it was found difficult to produce a balanced programme of general interest in half an hour, and from the 13th October, 1934, these transmissions were lengthened to ¾ hour. They continued in this form for almost another year, after which they were finally discontinued on the 11th September, 1935, in view of the impending high-definition service.

PART 2

EVENTS LEADING TO THE ESTABLISHMENT OF THE ALEXANDRA PALACE STATION

(a) The Television Committee's Recommendations

In order to understand the technical decisions, it is necessary to discuss the circumstances leading to the establishment of the Alexandra Palace station.

Having regard to the rapid strides which had been made in the technique of television, His Majesty's Postmaster-General in May, 1934, appointed a Committee under the Chairmanship of Lord Selsdon to consider the development of television and to advise him on the relative merits of the several systems and on the conditions under which any public service of television should be provided.

Having examined all the different systems of television in this and certain other countries this Committee reported in January, 1935, that the art of high-definition television had reached such a standard of development as to justify the first steps being taken towards the early establishment of a public television service of this type.

In view of the close relationship which clearly must exist between sound and vision broadcasting, the Committee recommended that the authority which is responsible for sound broadcasting—the British Broadcasting Corporation—should also be entrusted with the inauguration of the television service under the guidance of an Advisory Committee to be appointed. Consequent upon the result of its investigations the Television Committee further recommended that there should be an extended trial of two systems under strictly comparable conditions, by installing them side by side at a station in London where they should be used alternately and not simultaneously, for a public service.

The two systems in question were those of Baird Television, Ltd., and Marconi-E.M.I. Television Co., Ltd., both of which were in a relatively advanced stage of development and had already been operated experimentally over wireless channels with satisfactory results. The two companies were therefore to be given an opportunity to supply to the British Broadcasting Corporation the necessary apparatus to operate their systems.

The Committee stipulated that a standard of not less than 240 lines and 25 frames per sec. should be used, as this was considered to represent the minimum definition acceptable for the purposes of a public service.

The Television Committee further recommended that an Advisory Committee be appointed on which the Post Office, the Department of Scientific and Industrial Research, and the British Broadcasting Corporation, should be represented. This Committee was duly appointed and, in turn, deputed a number of its members to form a sub-committee to deal with exclusively technical matters.

(b) The Choice of Standards of Definition and Operating Wavelengths

The respective companies were invited to submit their views regarding the standard of definition which they would prefer to adopt.

Baird Television, Ltd., expressed their preference for the minimum standard acceptable to the Television Committee, viz. 240 lines and 25 frames per sec. sequentially scanned.

For 240 lines and 25 frames per sec. the effective upper limit of frequency generated by scanning was said to be about 1·5 Mc./sec., and it was suggested that any further increase in this frequency band resultant upon an increase in the number of lines or frames was not warranted, on the grounds that the cost and complication of the receiver would be unduly increased. The Marconi-E.M.I. Co. on the other hand desired to use 405 lines and 50 frames per second, interlaced to give 25 complete pictures per sec. They laid stress on the advantages of interlaced scanning on the grounds that it has the apparent effect of increasing the picture-repetition frequency to 50 per sec. at which no flicker is perceptible to the eye. This is achieved, however, without extending the band of frequencies beyond that which would be generated by 25 frames sequential scanning.

The greater number of lines proposed by the Marconi-E.M.I. Co. would of course increase the frequency band, but this, they maintained, would be justifiable in view of probable improvement in receiver technique in the future, which would permit the higher degree of definition transmitted to be effectively reproduced. The upper limit of frequency generated by this method of scanning was said to be approximately 2 Mc./sec.

The Advisory Committee gave the matter of standards close attention, but their efforts to arrive at a compromise in the form of a common standard of definition mutually acceptable to both companies were unsuccessful, chiefly owing to the advanced state of development which had been reached by the companies using their respective standards of definition.

In consequence the Advisory Committee decided that transmissions should take place on both standards of definition alternately. That is to say, during the period of transmission by the Baird system 240 lines and 25 frames per sec. would be used, while during the Marconi-E.M.I. transmission period the alternative standard of 405 lines and 50 frames per sec. interlaced would be employed.

Before reaching this decision the Advisory Committee assured itself that the two proposed standards of transmission could be received on a single receiver by means of a simple switching operation without unduly complicating or increasing the cost of the receiver.

It was hoped that a single radio vision transmitter might be constructed which would be suitable for both systems, but this was found not to be practicable, as the characteristics required by the two systems were so diverse as not to permit of the use of common apparatus other than the aerial and high-frequency feeder line.

Choice of Wavelengths.

The choice of a working wavelength for the vision transmitter was largely dictated by the very wide band of frequencies to be transmitted, as it would clearly be impossible to modulate any but an ultra-short wavelength with such a band of frequencies.

In general it is not practicable to operate a radio transmitter if the ratio of the carrier-wave fundamental frequency to the modulating frequency is much less than 20/1, otherwise the problem of ensuring adequate response at the side-band frequencies becomes too complicated.

This being so, a carrier wave frequency of 40 to 50 Mc./sec. is required for high-definition television, as it is called upon to accommodate modulation frequencies having an upper limit of about 2 Mc./sec.

Above 30 Mc./sec. there are no internationally-agreed wave-band allocations. The Post Office allocated the band between 40·5 and 52·5 Mc./sec. for the purposes of television, and the Television Advisory Committee decided that the London station should radiate vision on a frequency of 45 Mc./sec.

The accompanying sound could, of course from the technical point of view, be transmitted on any wavelength in the short, medium, or long bands, but owing to the congestion which exists, some difficulty would have been experienced in finding a channel for this transmitter, let alone any future transmitter of the same type. Moreover, in the interests of simplicity it is desirable that television receivers should be capable of picking up both sound and vision on one and the same aerial. For these reasons, therefore, the Advisory Committee decided that the sound should be broadcast on an ultra-short wavelength also, as close in frequency to the vision transmission as might be practicable, and a frequency of 41·5 Mc./sec. was chosen for this purpose.

This provided a separation of 3·5 Mc./sec., which was considered to be sufficient to prevent side-band interference between the two signals without encroaching more than was essential on the total wave-band available.

By such a disposition of frequencies, space is left at the higher end of the band for one more clear channel which will serve in the event of the erection of another station. It is believed that in the case of a third station situated more remotely from London, the original London sound and vision frequencies could be used without interference; while in the case of a fourth station, the same frequencies might be employed as for the second station, and so on, allotting the frequencies on a staggered basis. Whether this will be possible is not yet known, as insufficient data have yet been compiled regarding the area of interference caused by the London Television Station under all conditions of ionization of the upper atmosphere. Evidence at present makes it clear that reflection phenomena at 45 Mc./sec. exist, but their full significance is not entirely understood at present. Part 6, Section (*b*), deals with this aspect of the matter.

(c) The Choice of a Site

The choice of a site suitable for the London station presented a number of problems, and it was not an easy matter to find a situation where all the various requirements were adequately fulfilled.

In the first place it was necessary to use ultra-short waves for transmission, for reasons previously outlined. The effective range of ultra-short waves of this order of wavelength is known to be comparatively small—at one time it was thought not to extend beyond the optical range determined by the curvature of the earth's surface, although this has since been disproved. In consequence it is clear that the station must be situated as nearly as possible at the centre of the area of population which it is intended to serve.

Secondly, as is well known, the height of the transmitting aerial above surrounding territory is of cardinal importance in the service area of an ultra short-wave station, so that a most important requirement of the site was that it should stand on high ground and, further, that there should be no restrictions to the erection of a high mast to give a satisfactory elevation to the aerial.

Thirdly, a large area was necessary to accommodate the studios and rooms for the scanning and transmitting apparatus required for the operation of the two systems.

The first and most obvious site for the station is in the centre of the city, but, apart from the fact that no very high ground exists in the centre of London, this situation could not be contemplated, as it would not be permissible to erect a high mast and also the cost of acquiring a sufficient area for the needs of the station would be prohibitive.

Attention was therefore turned to high ground lying some distance from the centre, and a careful study was made of those parts sufficiently elevated to be of interest.

Hampstead and Highgate appeared to offer promise, but it was found that the acquisition of an area sufficient for the purpose in these districts would have been very costly, and severe restrictions existed regarding the erection of high masts.

High ground in the South of London, notably near the Crystal Palace, was considered, but in this case it was felt that the greater part of the service area of the station would be too much displaced in a southerly direction. Such places as Shooter's Hill were ruled out, on the grounds that they were too far from the central residential districts.

The Alexandra Palace site, however, appeared to possess outstanding advantages in that the ground-level

was satisfactorily high, being 306 ft. above sea-level. There was a great deal of available space in the building, and Governmental permission to erect a sufficiently high mast was obtainable.

Another factor which weighed in favour of the Alexandra Palace site lay in the fact that the Palace stands on the top of an eminence so that the ground falls away very rapidly in all directions, and is comparatively low-lying all round, particularly in the direction of the centre of London. It was thought likely that this fact would give very low local attenuation, and some experimental evidence bearing upon this assumption is referred to in Part 5, Section (*c*). A 6 in. to the mile relief contour map of Greater London was constructed, and from this it was clear that with this site for the transmitter the number of areas in which weak signals would be likely to be encountered, owing to the overshadowing effect of high ground, would be a minimum over the whole of Greater London.

The Alexandra Palace site was accordingly chosen, and subsequent experience has confirmed the wisdom of the choice. This, however, will be dealt with later in the paper.

(d) The Beginning of the Service, and the Adoption of a Single Standard of Definition

The first transmissions from Alexandra Palace on both systems took place early in August, 1936, and demonstrations were given at the Radio Exhibition at Olympia between the 26th August and 5th September of that year. A period of "trial programmes" followed, and the television service was formally opened by the Postmaster-General on the 2nd November.

It was found that in practice the use of two standards of definition involved many disadvantages, from the point of view both of the manufacture and of the operation of receivers. In response to strong representations from many quarters, the Television Advisory Committee decided that it was essential in the interests of television, and to make possible the simplification and reduction of cost of receivers, to adopt a single standard of working.

It was further found that the impression of flicker associated with the use of 25 frames per sec. sequentially scanned gave rise to criticism on the grounds of eye strain, so that the superiority of interlaced scanning at 50 frames per second, giving 25 complete picture scans per sec., was clearly established.

In consequence the Television Advisory Committee decided that transmissions from Alexandra Palace should be carried out on a single standard of definition, viz. 405 lines and 50 frames interlaced, giving 25 complete picture scans per second. A public announcement to this effect was made on the 5th February, 1937.

PART 3

GENERAL DESIGN OF THE STATION

(a) General Plan of the Accommodation

The portion of the Alexandra Palace buildings taken over by the British Broadcasting Corporation consists of the S.E. tower with about 30 000 sq. ft. of adjacent premises in which the station proper is situated. The N.E. tower and theatre comprise a further superficial area of about 25 000 sq. ft.

The S.E. tower was converted to provide offices for the technical, production, and administrative staff, and it also serves as a base for the aerial mast. The existing pylon top and floors were removed, and fire-resisting floors and staircase were installed to provide five floors of offices above the ground floor.

The floors were carried by steel members, and the main brickwork of the tower, which is 85 ft. in height, was tied horizontally by steel ties at each floor, thus producing a structure of great solidity on which the mast could be erected. By means of these alterations the floor area available was increased by some 8 000 sq. ft.

With the exception of the structural modifications to the tower, the premises in general required little alteration from a structural point of view to adapt them for the equipment which they were to contain. Certain additional partitions were required, and it was necessary to segregate the premises from the remainder of the Palace buildings by means of a fireproof partition to fulfil the requirements of the local authorities.

Fig. 3 shows the layout of the S.E. premises. On the ground floor the base of the tower provides an entrance hall which forms the main entrance. Behind the tower is the local electricity substation and distribution switchgear room, the associated transformers being of the outdoor type and situated immediately outside the building.

The premises west of the tower provide two large halls each 70 ft. × 50 ft. to accommodate the Marconi-E.M.I. and Baird vision transmitters respectively, while in a central third hall 56 ft. × 24 ft. is situated the Marconi sound transmitter. Air-blast coolers for the water supply to the cooled-anode valves in all three transmitters are situated on the colonnade in front of the main premises, suitable chambers having been formed by bricking up the existing colonnade arches.

Behind the sound transmitter is a fully equipped theatre 40 ft. × 15 ft. for the projection of sound films, which is used by the productions staff for the selection and timing of excerpts from films which it is proposed to use for television purposes.

At the west end of the ground floor is a scenery-storage space 52 ft. × 22 ft. with a wide and lofty entrance from the terrace, into which large pieces of scenery and other bulky objects can easily be brought. This space can also be used as a temporary studio to televise objects whose weight or bulk precludes the possibility of their being taken to the studios on the first floor. A basement beneath accommodates the boiler for the heating system.

At the extreme rear of the premises is situated a restaurant for the staff, together with the necessary kitchens and storage rooms.

On the first floor there are two main studios each 70 ft. × 30 ft. and 27 ft. high, one for use with the Marconi-E.M.I. equipment, and the other originally used for the apparatus for the Baird intermediate film process and electron camera.

Between the two main studios are two control rooms, one associated with each system, a small studio and scanner room for the Baird spotlight scanning process and a room housing the Baird apparatus for film scanning by mechanical means.

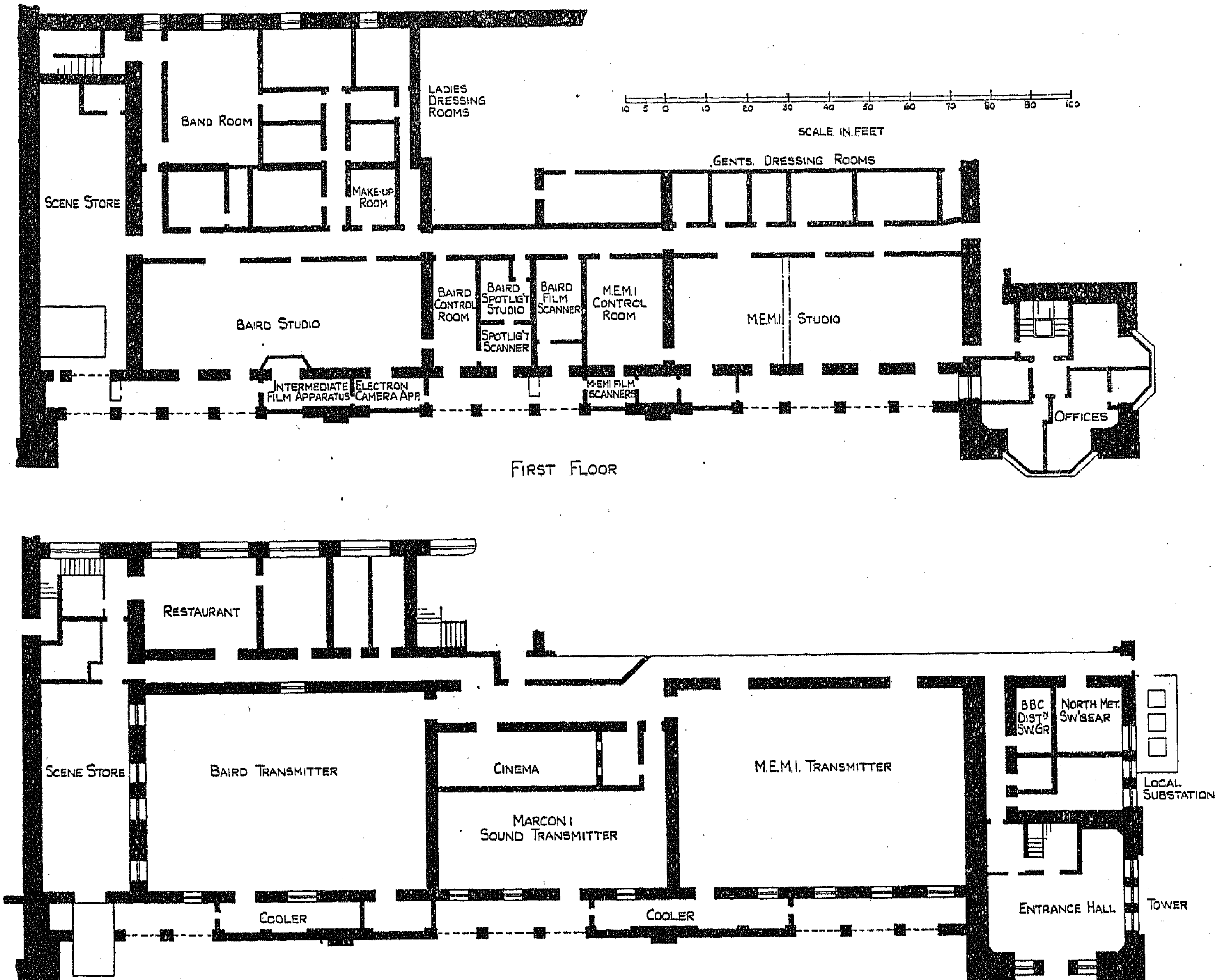

Fig. 3.—Plan of London Television Station.

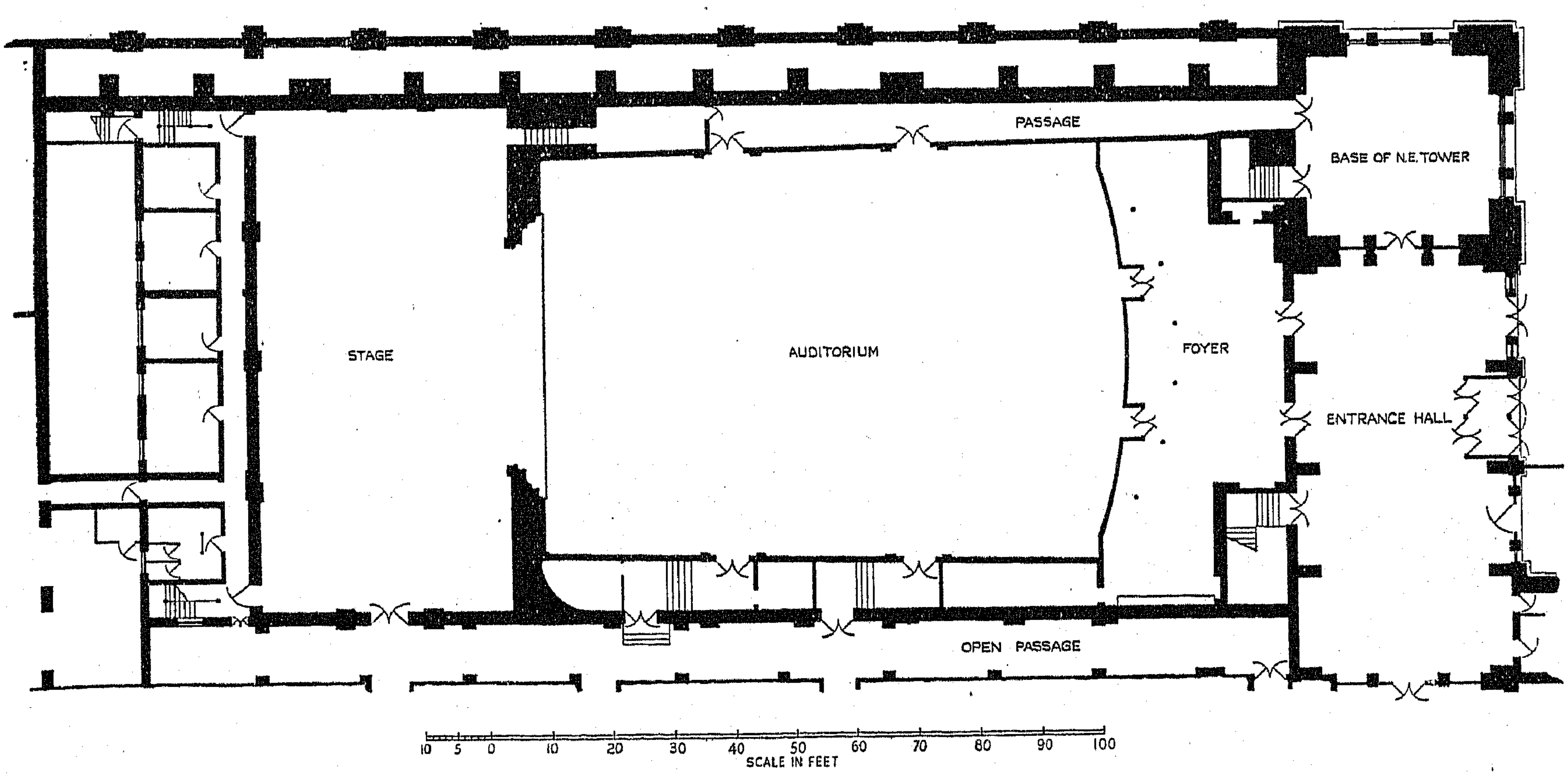

Fig. 4.—Plan of theatre area.

Film scanning by the Marconi-E.M.I. process is carried out in an annexe to the control room, built on the first-floor colonnade.

The rear portion of the premises is devoted to dressing rooms for male and female artists, a make-up room, and a band instrument room. The west end of the premises provides a second scenery store similar in dimensions to and immediately above the store on the ground floor, a floor trap and travelling gantry with block and tackle being provided to raise scenery from the ground floor to the first floor.

The scenery which is required for current productions only is stored in these spaces, the bulk of the scenery being at present stored in the north-east theatre premises.

Since the decision to adopt a single standard of definition, the Baird studio has been brought into use as additional production space for transmissions on 405 lines and 50 frames interlaced.

Fig. 4 depicts the theatre premises, and it will be observed that considerable space for possible future extension of studios exists in this area.

(b) Arrangement of Electrical Supply

The electricity supply for the Alexandra Palace installation is taken from the North Metropolitan Electric Supply Co.'s system. A ring main in the form of two feeders exists between the Alexandra Palace local substation and the Wood Green traction substation via the supply company's substation at Ringslade Road. The Wood Green substation in turn is fed by alternative routes from the supply company's power station at Brimsdown, and thus continuity of supply is amply assured. Supply is at 11 kV, 3-phase, 50 cycles per sec., and distribution is at 415 volts, 3-phase 4-wire, with earthed neutral.

(c) Acoustic Treatment of Studios

As has been stated, the two main studios are 70 ft. long, 30 ft. wide, and 27 ft. high, and their acoustic treatment has called for careful consideration.

It was considered that the acoustic properties desirable in a studio intended for television should differ from those sought after in a studio exclusively used for sound broadcasting.

In the latter case, the ear is the only criterion of the reproduced performance, and the effect produced can be materially enhanced by the artistic introduction of a certain degree of reverberation or echo. Such effects, however, require careful arrangement of the performers before the microphone so that a pleasing balance of sound is obtained. Moreover, the degree of reverberation which is acceptable varies widely with the type of performance —thus a studio suitable for a variety performance would not be suitable for a symphony orchestra, and, in general, different studios are used for different types of programmes. Above all, the placing of the performers from an appearance point of view is a matter of complete indifference in sound broadcasting, so long as a correct sound balance is maintained.

In the case of television, however, it is an entirely different matter, as the proper location of performers from the point of view of appearance is of paramount importance in the interests of artistic production, so that sound requirements must, of necessity, be subservient to this consideration. Added to this, it is not at present economically possible to provide a series of studios of divergent acoustic properties, each fully equipped with the manifold requirements of television.

Consequently, studios designed for general purposes were required, adapted for a wide range of scenic presentations varying from an intimate *tête-à-tête* to an elaborate and extensive production. In order that the sound accompanying scenes of such widely divergent character should be of uniformly good quality, and in the absence of much experience in television technique, it was thought desirable to design the acoustics of these studios on the basis of film-studio technique, that is to say, to make them as little reverberant as possible, and to allow the temporary sets built up as scenery to provide local reverberation for each particular scene. Film-studio practice is to cover as much as possible of the walls and ceiling with a highly absorbent material such as mineral wool. A convenient and less expensive alternative was found in the form of 2 ft. square slabs of asbestos felt about 1 in. thick. The original specification, therefore, was to cover the whole of the wall and ceiling surfaces with this material, stuck in contact with the plaster work. A form of sound-proof shutter was specified for the windows, consisting of a wooden framing, boarded on both sides, pugged with sawdust, and covered on both sides with canvas-covered acoustic quilt. The floor was to be untreated acoustically.

In practice, various modifications were made to this specification. One of the long walls of each studio, that on the north side, was found to be of lath-and-plaster construction unsuitable for direct application of asbestos felt, and it was necessary to support the slabs other than by sticking them to the plaster. To a height of 5 ft. from the floor the walls were close boarded before the application of the slabs. Above this height wooden battens were erected at 2 ft. centres, and the asbestos-felt slabs were nailed to these.

The original lath-and-plaster ceiling was demolished and $\frac{1}{2}$-in. building board was nailed directly to the existing joists. At a later stage, the asbestos felt was found to be easily damaged and it was therefore covered to a height of 10 ft. with a light scrim which appears to have negligible effect upon the sound-absorbent properties of the material beneath.

Fig. 5 is a curve showing reverberation time plotted against frequency for one of the main studios, taken with nothing in the studios but the main fixtures. There is but little difference between the two main studios from an acoustic point of view.

The measurements of reverberation time were taken by means of a piece of apparatus which enables the actual decay of sound to be accurately recorded on a logarithmic scale on a moving strip of wax paper.

In view of the complex nature of the acoustical treatment of the studios in their final form, it is difficult to interpret the curves in relation to the absorbing properties of the various materials employed. Fig. 6 shows the absorption/frequency characteristics, as measured in a reverberation chamber, of asbestos-felt slabs fixed

directly to a hard surface and fixed to wooden battens respectively. On the basis of these measurements, reverberation curves rising very considerably for frequencies below 500 cycles per sec. would be expected. Whilst it is probable that for this, as for other materials, some modification has to be made to the absorption curves obtained in a small reverberation chamber in order to render them strictly applicable to a moderately large studio, such modifications would not be sufficient to account for the low reverberation time actually found at these frequencies in the completed studios. It is quite probable that both the lath-and-plaster north wall and the lightly-constructed building-board ceiling are providing considerable low-frequency absorption, while possibly the effect of the relatively large area of window shutters has also to be taken into account. No data are available to enable any analysis of these effects to be made.

As a result of the reverberation/frequency characteristics which have been obtained from the finished studio, the quality of the sound broadcast with the television is in general satisfactory over a large range of subjects.

(d) Production Lighting

The lighting of studio scenes for television presentation appears to demand the development of a technique which, while akin to both theatrical and film-production lighting technique and embodying something of both, nevertheless is not exactly similar to either in its entirety.

The reason for this lies in the fact that a television programme is in effect produced before an audience, just as is a stage production, and, consequently, equal continuity of action is necessary. The condition is therefore imposed that the production lighting must, in the main, be on continuously from start to finish, as in a stage presentation; and not intermittently as is usually the case in film studios, where isolated scenes are recorded and afterwards edited and knit together into a continuous whole.

This fact brings several difficulties in its train. First, all production lighting supply equipment must be rated to operate over comparatively long periods; secondly, the projectors and floodlights must themselves be capable of operating for a protracted period without overheating; and thirdly, the ventilation of the studio must be capable of dealing with the continuous dissipation of power involved in high-intensity lighting.

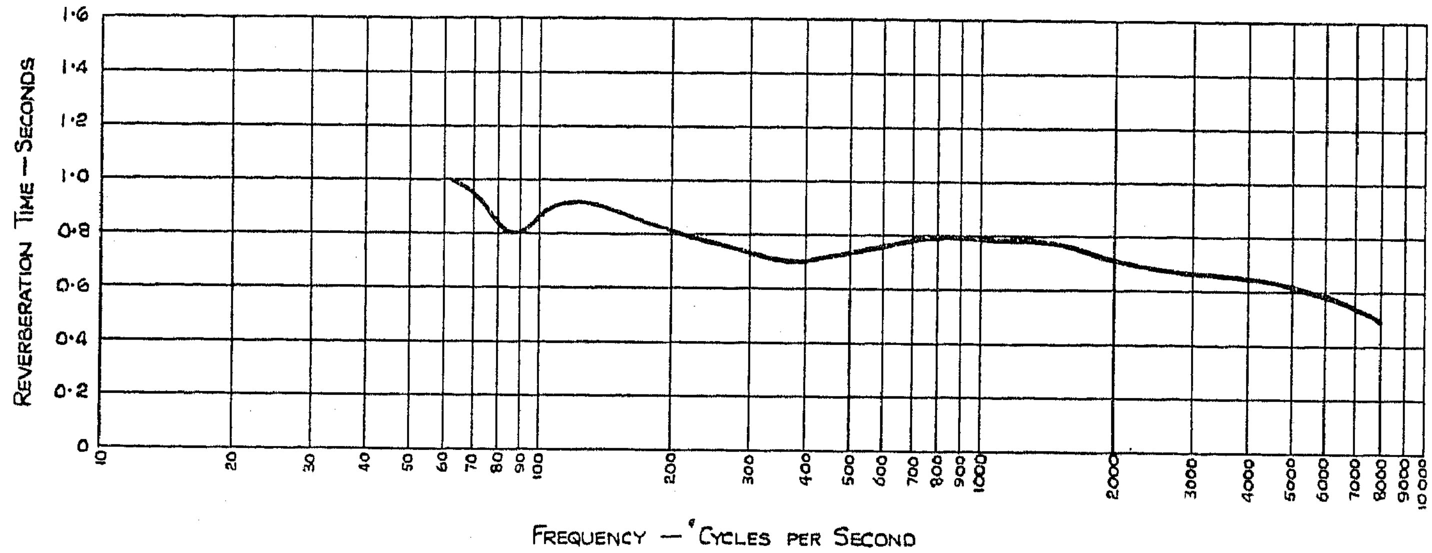

Fig. 5

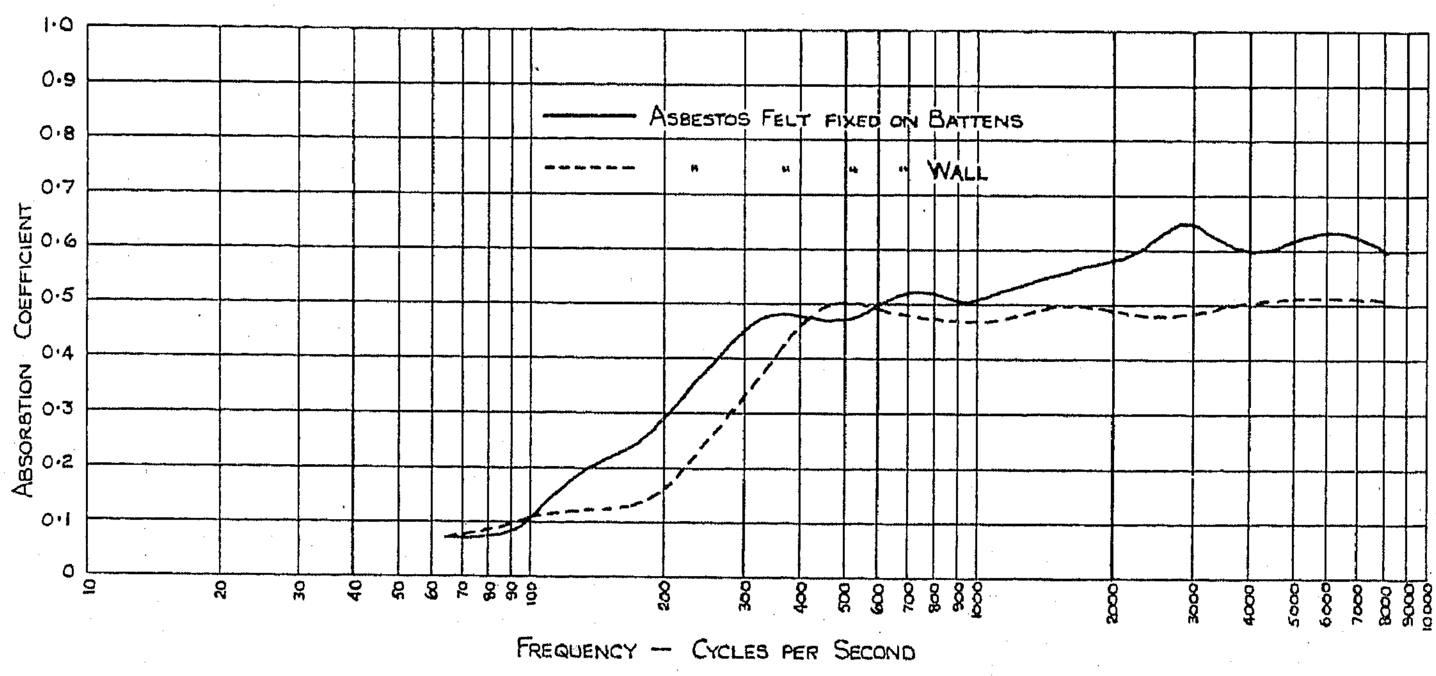

Fig. 6

The first point means that it is not possible to economize by specifying a short-time rating for conversion plant and wiring, as is not uncommon in film-studio lighting installations, but rather implies that all lighting equipment must be continuously rated, as apart from the actual use of studios for transmission, a great deal of time is involved in fully lit rehearsals owing to the ever-changing nature of the productions necessary for a day-to-day television service.

The second point means that the design of projectors, spotlights, etc., must be carefully considered with a view to securing extra ventilation and means for conduction of heat generated, otherwise the wastage factor for lighting appliances is liable to be very high indeed.

The question of studio ventilation is covered in a later Section of the paper.

In general, the types of incandescent studio illuminator used for film-studio work have proved equally satisfactory for television, and lens and mirror spotlamps in powers of 500, 1 000, 2 000, and 5 000 watts, together with multiple lampfloods of from 3 000 to 15 000 watts, have all found their place in the television studio.

It has been necessary to modify to some extent the arrangements for ventilation in some types of lamps, as previously remarked, in order to cater for the longer periods of operation involved in television as against the use for which they were originally designed, viz. the film studio.

Arc-lamp illuminators have not been used to any great extent up to the present, chiefly on account of their tendency to give sudden fluctuations in the total amount of light falling on the scene, a feature which is very objectionable from the television point of view. In addition, the fumes from arcs are inconvenient if the latter have to be operated for lengthy periods in any but a very large studio, and arcs also require frequent attention during production.

The supply to all incandescent lamps has been standardized at 110 volts, being the voltage used by almost all film studios, and hence bulbs are readily obtainable in all wattages at this voltage.

The advantages which, in general, have led to the use of 110 volts instead of a higher voltage are manifold. Amongst other things the use of low-voltage high-current lamps has resulted in a smaller filament structure which is more rigid and hence less fragile, and also approximates more closely to a point source.

In order to reduce ventilating problems and give more comfortable working conditions for the artists, attention has been turned to lamps of the water-cooled gaseous-discharge type. Experiments will be carried out to determine the suitability of this type of illumination to television studios, and it is hoped that by a suitable combination of incandescent and gaseous-discharge lamps, the heating effect of close lighting can be materially reduced.

The actual arrangement of lighting units for any given scene in the studio approximates very closely to that adopted for a similar scene in a film studio.

A certain general level of lighting is attained by the use of floodlamps, after which the artists and scene to be televised are lit in detail by means of spotlamps, the exact arrangement and direction of lighting depending a good deal on the nature of the scene. High-angle lighting from the top, back, and sides, is used to give depth to the scene, and modelling achieved by the use of further spotlamps judiciously placed at floor-level. Delicate shading on the features of artists in close-up is achieved in general by the use of low-intensity diffused frontal lighting.

Lighting for television has something in common with lighting for the production of film by some colour processes, in that a fair amount of attention has to be paid to uniformity of illumination. This implies that a good deal of care has to be taken to avoid excessive overlapping of the illumination areas of several spotlamps, because departures from uniformity of illumination so caused while not perceptible to the eye, and often of not much significance when ordinary negative is being exposed, are readily discernible when the scene is viewed with a television camera, much in the same way as they are in the process of photographing colour film.

Studio scenes for television are normally illuminated with an average intensity of about 150 to 200 ft.-candles.

Alternating current is used for the Marconi-E.M.I. studio lighting at Alexandra Palace, and its use does not introduce any flicker into the televised picture, partly as a result of the thermal smoothing of the lamp filaments themselves, but largely because the 50-cycle frame frequency of scanning is so arranged as to be synchronized with the 50-cycle mains supply.

The Baird equipment, on the other hand, operating at a frame frequency of 25 cycles per sec., required the use of direct-current studio lighting for the intermediate film process and electron camera. The necessary supply was obtained from two motor-generators operated from the 415-volt supply mains, giving an output of 300 amperes each at 110 volts.

The detailed arrangement of production lighting equipment in the studios will now be considered.

The Marconi-E.M.I. Studio

The power supply is taken from the main distribution switchgear through a separate feeder and oil circuit-breaker to the primary of two 45-kVA 3-phase transformers, the secondaries of which are arranged for 110-volt 3-phase, 4-wire working. Both transformers are located in the Marconi-E.M.I. vision transmitter hall immediately beneath the studio.

The secondary side of one transformer is connected to a theatre-type lighting switchboard, which controls 24 separate circuits. The circuits are divided into three groups, each group being supplied by one phase and neutral from the transformer. Each circuit has a maximum load of 2 000 watts, and is provided with dimming and pre-selective black-out features.

Bank and differential dimming with any desired combination of circuits can be carried out, and any number of circuits can be pre-set so that they can be blacked out by means of a remote-operated contactor.

The output of the second transformer is taken to an adjacent remote-operated contactor board carrying nine single-pole contactors arranged in three groups of three, each group being connected to one phase and neutral of the transformer. Each circuit thus has a maximum loading of 5 000 watts and is controlled by a push-button switch on the lighting switchboard previously described.

No dimming or bank black-out features are provided in the case of these circuits.

All circuits are run to appropriate positions in the studio and terminate in sockets, to which illuminators may be connected by flexible cables fitted with plugs.

Plugs of different sizes are used for the 2 000- and 5 000-watt circuits so that there is no risk of overloading the former, while the latter can each be loaded to capacity either by the use of a single 5 000-watt illuminator, or by a number of lamps of lower power attached through the medium of multiple adaptors.

Fig. 7 shows the arrangement of the lighting appliances in this studio, from which it will be noted that the acting space is concentrated towards the eastern end. The area at the opposite end accommodates the orchestra and affords a certain amount of working space.

Extending around the three sides of the acting space bounded by studio walls is an erection of builders' steel scaffolding, which forms a lighting gallery at a height of 14 feet. This gallery is continued in the form of a bridge of steel-lattice construction, across the studio in front of the acting space.

The extreme flexibility of the steel-scaffolding construction is of manifest advantage, as extensions can be quickly fitted wherever necessary and illuminators clipped on by means of a fitting developed for the purpose at any height or angle to meet the requirements of some particular production.

The majority of the supply plugs are situated at lighting gallery level, as the bulk of the lighting power is concentrated in illuminators giving high-angle lighting. A number of overhead battens are provided, which can be lowered to floor-level for fitting up, and which serve to support the multiple-lamp floods used to afford the necessary diffused general lighting. These battens are provided with a number of circuits fed by flexible cables hanging from the ceiling and terminating in plugs on the battens themselves. Fig. 8 (see Plate 1, facing page 744) depicts a typical studio production scene.

The Baird Studio

The lighting arrangements in this studio are very similar to those in the other, and there again the system is divided into two parts. A theatre-type switchboard controlling 30 2 000-watt circuits is installed having identical facilities with that installed in the other studio, except that the supply is obtained from the two 300-ampere motor-generators previously described.

The second part of the system consists of a 45-kVA 3-phase transformer with 9-way remote-operated contactor board, situated in the Baird transmitter hall, feeding nine 5-kW distribution sockets in the studio, all arrangements being identical with those previously outlined for the similar portion of the equipment in the other studio.

The practice of mixing d.c. and a.c. studio lighting may, on first sight, appear unusual, but there is no valid reason why it should not be done, as the two parts of the system are entirely separate.

The layout of the studio differs but little from that depicted in Fig. 7, except that the lighting bridge traversing the studio is omitted. The arrangement of steel scaffolding for back and side lighting galleries is precisely similar in both cases.

(e) Studio Ventilation

The ventilation of a television studio is a matter which requires some consideration and, in general, involves problems which are not met with in the broadcasting studio and probably only to a lesser degree in the film studio.

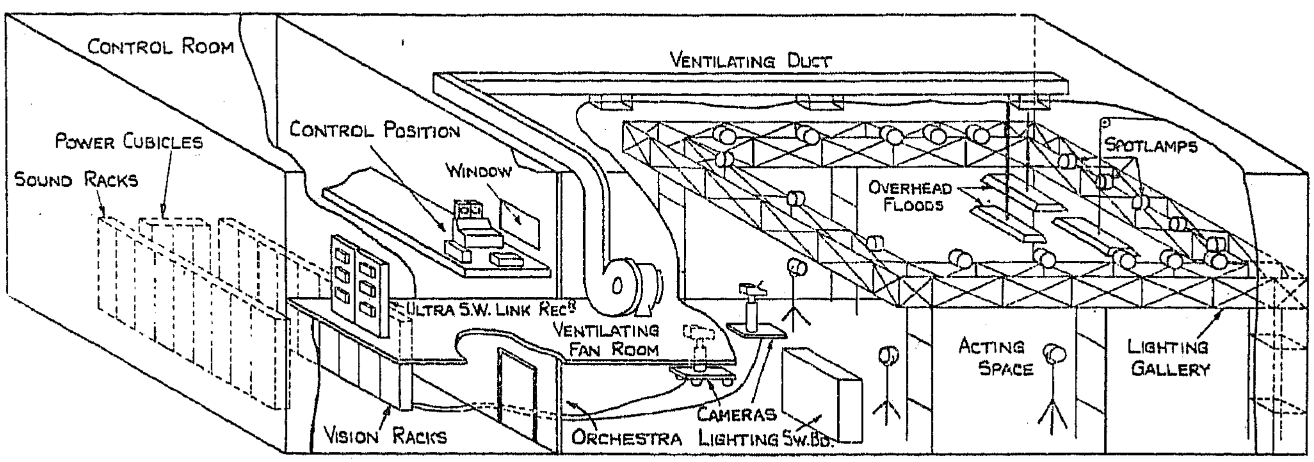

Fig. 7.—Diagrammatic layout of studio and control room, showing arrangement of production lighting.

In order to ensure adequate ventilation it is necessary to change the air in the studio with sufficient rapidity to carry away the heat due to production lighting without the introduction of noise from the ventilating machinery, which would be picked up by the studio microphones.

In the broadcasting studio the question of noise is of course equally important, but the absence of intense lighting, involving large dissipation of power, materially eases the problem, because the number of changes of air required per hour are very much fewer.

In the average film studio the ventilation problem is in general easier than in the present Alexandra Palace studios, because of the shorter times during which full lighting is in use, and also because of the greater volumetric contents of the average film stage. The particularly significant factor in this is the great height which is usually encountered, and which allows heated air from the lighting to rise to the top part of the chamber, where it accumulates during the shooting of a scene and is gradually removed by the ventilating fans during the subsequent period when no lighting is in operation.

In these circumstances the air at floor-level normally remains fairly cool, and continuously-operating ventilating machinery of moderate proportions proves quite

adequate to exhaust the periodically replenished accumulation of heated air.

Ideally, of course, the studio should be provided with conditioning and refrigerating machinery in addition to the mechanism for changing the air, so that when the outside temperature is high in summer, the incoming air may be rendered quite clean and cool before its introduction into the studio. In the case of the Alexandra Palace installation no refrigerating machinery is provided, as it was felt that it was justifiable to dispense with it on economic grounds.

Each studio is provided with a separate ventilating system, the two equipments being similar in construction and disposition. Ventilation is effected by extracting the heated air from the upper part of the studio through three square grilled openings situated on the centre line of the ceiling and equally disposed along the length of the studio.

These outlets are connected by sheet-metal trunking, lined with acoustic board to minimize the transmission of noise, to a centrifugal fan capable of a maximum continuous duty of 10 000 cu. ft. of air per minute, giving approximately 12 changes of air per hour. The fan is driven by a 3-phase commutator motor with movable brushgear, giving a speed variation of 200 to 960 r.p.m.

The brushgear is controlled, through the medium of wire ropes running over pulleys, by means of a handwheel situated in the studio, and the speed variation so afforded gives adequate control of ventilation over a large range of lighting loads and conditions of outside temperature.

The incoming air to each studio is drawn from the colonnade through a series of specially constructed inlets, these taking the form of acoustic labyrinths designed to allow free passage of air while minimizing the ingress of sound from the outside.

The method of ventilation adopted differs from that used in the sound studios at Broadcasting House, as in this case conditioned air is introduced at the top of the studios and the displaced air allowed to escape through openings at the bottom. The object of this procedure is to avoid as far as possible the creation of draughts.

In the case of the Alexandra Palace studios, however, so much heat is generated by production lighting that it would not be satisfactory to oppose the resultant strong convection currents of heated air by artificially reversing the natural direction of air circulation.

(f) Studio Development

Some attempt will be made in this Section to forecast the general lines upon which the development of studios is likely to take place. It must be made clear that the following is based on proposals which are at present receiving consideration but in regard to which no definite decision has been made.

It is desirable when contemplating the extension of production facilities at Alexandra Palace to have continually in mind the requirements of extensions in the more distant as well as the immediate future. At present there are, as has been stated, two main studios of equal size, both equipped with comprehensive lighting systems, and under existing circumstances both these studios are operated from a single control room which provides facilities for the operation of four studio cameras and two film-scanning cameras simultaneously. The bulk of the production at present takes place in the east studio (the Marconi-E.M.I. studio) and the west studio (originally the Baird studio) is used as an annexe for further productions on occasions when requirements exceed the capacity of the east studio. Moreover, the control-room apparatus is so arranged that simultaneous working in both studios is not possible, and considerations of space in the existing control room preclude the possibility of extending the apparatus sufficiently to permit of this facility.

It is clear that only one actual transmission can be carried out at any one time owing to the existence of but one vision transmitter, but, nevertheless, it would be advantageous if a locally viewed televised rehearsal could be conducted in one studio while the other was on transmission, or, alternatively, simultaneous rehearsals conducted in both studios.

A further advantage would be gained by increasing the number of studios to three, and it is desirable that the third studio should be a good deal larger than those at present existing. The Alexandra Palace theatre has much to commend its use in this connection, as the available floor space is many times greater than that of the present studios, and experience has shown that the area of these is insufficient to permit of convenient working when productions of any magnitude are carried out.

The exact manner in which the studios would be arranged from the point of view of the television apparatus calls for very careful consideration, and it is essential that each should form part of a cognate scheme of working, which, although it might not be possible on economic grounds to complete it at one time, could be gradually built up as time went on.

Such a scheme has therefore been drawn up. It provides that each studio should be a complete unit with full production and rehearsal facilities, provision of film-scanning apparatus, and everything necessary for the production and monitoring of a televised performance or rehearsal, with accompanying sound.

The outputs from all studio units would then be brought into a central control room where facilities for pre-viewing the picture and pre-hearing the sound from each studio would be available, and a master-control position would be established. The master-control position would be provided with means for fading from one studio to another, both vision and sound as required, or making such superimpositions or dissolves as might be necessitated by the nature of the programme.

A further function of the proposed central control room would be to carry out the introduction into the radiated programme, at appropriate times, of television outside broadcasts coming from points remote from Alexandra Palace. The question of these outside broadcast transmissions is dealt with later in this paper.

In addition to the central control room, it is considered desirable that a centralized synchronizing signal-generating equipment should be provided, so that all sources of vision signal local to Alexandra Palace would be supplied with synchronizing impulses from a common source and superimposition of one upon the other could be carried out without difficulty.

PART 4

DESCRIPTION OF EQUIPMENT

(a) Marconi-E.M.I. Studio Equipment

This paper is not intended to include a detailed technical description of the apparatus; consequently, attention will be directed towards its operation rather than its principles of design.

The Marconi-E.M.I. system centres around the Emitron transmitting tube, which is a photo-electric device incorporating a light-sensitive mosaic scanned by means of an electron beam. Emitron tubes are built into portable cameras resembling, and used in a similar manner to, motion-picture cameras.

The Marconi-E.M.I. studio is equipped for the transmission of vision with four such cameras and their associated circuits. In addition, for the transmission of film which may either be required separately or as a composite part of studio production, there are two sets of film scanning apparatus in which the film is reproduced by a standard motion-picture head mechanism, the resultant image being projected through a suitable optical system directly on to the mosaic plate of an emitron tube, contained in a camera which in other respects is similar to those used for studio purposes. The sound is reproduced by means of a sound head of conventional design. A detailed description of this device is given in another paper.* There are, thus, in all six cameras, all of which are identical as regards their design and that of their auxiliary apparatus.

With each camera is associated a camera channel, which is a chain of apparatus enabling the control to be effected of all variables associated with each individual camera. These include the intensity and focus of the Emitron scanning beam, the width, height, and exact location of the scanned area, the tilt and bend waveforms which are injected for the correction of illumination errors, and the gain of each channel. There are also controls which take account of the finite time of transmission of the scanning wave-forms and vision signals along the camera cables, which transmission times will, of course, vary with the lengths of cables in use.

It is desired to be able to transmit any one of the pictures emanating from the six cameras, or in some cases more than one simultaneously, this being known as superimposition and being a favourite presentation device. It is a fundamental principle of presentation technique that more than one camera should be used in a studio production, the transmission being frequently changed from one camera to another in order to increase production facilities, and it is therefore desirable to be able simultaneously to observe the picture derived from any camera not on transmission so that all the necessary technical adjustments may be made before it is introduced into the transmission.

To accommodate these requirements of the London Television Station, three groups of apparatus known as "picture channels" are provided, which are linked with the six camera channels by means of an intermediate unit known as the "fading and monitoring mixer." By means of this unit the picture from one or more cameras may be introduced into the transmission and simultaneously observed upon a viewing monitor. At the same time the picture from any other camera may be connected to the second picture channel and a preview thereby obtained on a further viewing monitor associated with this channel. The third channel fulfils two functions. It enables the transmissions of film which are made every morning for the benefit of the radio industry to be carried out without interfering with a rehearsal which is proceeding at the same time, and which is using the other two picture channels. At other times it constitutes a spare channel.

The transmission of the sound associated with the programme is catered for by the provision of five moving-coil and three ribbon microphones in the studio. In addition there are, of course, the sound heads of the two telecinė projectors, and there are two gramophones by means of which interval music and effects may be introduced. Each of these 12 sources has its own pre-amplifier at the output of which the signals are in all cases approximately at zero level. After control at the sound-control desk, which will be described later, the signals pass into main amplifiers, and thence by distribution circuits to the transmitter and to subsidiary amplifiers for the operation of various monitoring loud-speakers.

This equipment, together with its associated H.T. and L.T. supply apparatus, is mounted in three rows of bays on the ground floor of the control room adjoining the studio, as shown in Fig. 9 (see Plate 2). The control room is 30 ft. long, 22 ft. wide, and 24 ft. high. At a distance of 15 ft. 6 in. from the ground a gallery is provided with a window looking into the studio. Behind this window are grouped a number of control positions from which the presentation of the programme can be handled. In the centre sits the producer and the senior studio engineer. In front of each is a microphone by means of which instructions may be given to the camera operators, the studio sound engineer, the electricians, and the studio manager, all of whom are provided with headphones. By means of a row of control keys such instructions can be given to any of the above engineers singly, or by depressing a master key to all those provided with headphones. Behind the producer sits the vision mixer, whose function is to introduce the various cameras into the transmission as required by the producer. In front of the producer is the sound-mixing desk, which receives the inputs from the 12 sound sources. The desk is operated by the sound mixer who, as in the case of the vision mixer, introduces the various sound sources whether they be microphones, gramophones, or film sound-tracks, into the transmission as directed by the producer. The sound-mixing desk is provided with separate balancing and fading controls. By means of the former the level of any sound source can be adjusted to the correct value, so that it can be rapidly introduced if required by operation of the fade control. Adjoining the sound-mixing desk is the sound-control position, at which the volume of the sound sent to the transmitter is manually adjusted. The control gallery also carries the gramophone position, so that its operator is in easy touch with the producer. There are also provided a pair of viewing monitors, one for the transmission and one for the preview circuit, and a loud-speaker so that the producer and all the engineers on the control gallery can

* C. O. Browne (see page 767).

see and hear what is being radiated and at the same time observe the studio through the window.

It will be seen that what might be termed the programme control is carried out from the gallery, whereas the more detailed adjustment of the vision and sound circuits is carried out by a group of engineers associated with the vision and sound racks on the ground floor. A signal system is fitted between the vision mixer and these racks so that he can call for any camera to be placed on the preview channel. A system of cue lights operated by push-buttons under the control of the producer is fitted to enable him to signal announcers and the conductor of the orchestra when to commence.

In the majority of productions the various vision and sound units will be distributed in the following manner. Camera No. 1 is usually in the centre of the studio on a mobile truck which enables "tracking" shots to be done. Cameras 2 and 3 may cover the main scene from alternative view points, or they may be set for smaller side sets. Camera 4 is usually reserved for announcers and captions. The sound from the main scene is covered by means of a moving-coil microphone suspended from a microphone boom, which enables it to follow the movements of artists. The orchestra, usually situated at the near end of the studio under the window, is taken on a ribbon microphone, and there will in general be one or two other microphones at suitable points in the studio, such as the side sets. A viewing monitor is also provided in the studio, so that, for such productions as dress shows, the announcer can give a commentary while observing the picture which is actually being radiated.

(b) Marconi-E.M.I. Vision Transmitter

This is situated in a large hall on the ground floor, as illustrated in Fig. 10 (see Plate 1).

The carrier frequency is originated by a master oscillator and doubler, the master oscillator operating at half the carrier frequency, or 22·5 Mc./sec. This is then amplified by six stages of amplification in cascade. The transmitter is contained in three cubicles, of which the first comprises the master oscillator doubler and the first four stages of amplification. The second cubicle contains the fifth amplifier, which delivers some 2 kW of radio-frequency power to the grids of the sixth amplifier; this is mounted in the third cubicle.

Mixed vision and synchronizing signals from the control room, having a picture/synchronizing ratio of 1/1, are fed to the modulator by means of concentric cable, and at its input they have an overall amplitude of some 10 volts. The modulator contains effectively four stages of amplification, between the first two and the last two of which are d.c. couplings. Between the second and third stages, however, the d.c. component is lost and is subsequently restored with a very great degree of perfection. At the output of the modulator the signals have an overall amplitude of some 2 000 volts, and the picture/synchronizing ratio is unchanged at 1/1. They are then applied to the grids of the sixth amplifier, and grid modulation is effected. Owing to the nature of the modulation characteristic of the sixth or modulated amplifier, the picture/synchronizing ratio becomes modified in the course of modulation to the desired ratio of 70/30.

The H.T. supply to the modulator valves is obtained from a motor-alternator set having an a.c. output of 500 volts and 50 kW at 500 cycles. Each of the four stages has its own H.T. rectifier, which, in the case of the first three stages, incorporates hard valves, but in the case of the last stage employs a mercury-pool rectifier. For the filament heating-current for the first three stages various supplies are used, including 500-cycle and 50-cycle alternating current, and direct current obtained by rectification from the 500-cycle supply. The two valves in the last or modulator stage have individual filament-current d.c. generators, that for the last stage being insulated from earth as the filament is at high potential.

Filament current for all radio-frequency valves other than the master oscillator is obtained from a motor-generator set which has an output of 400 amperes and 24 volts. The master oscillator filament is applied separately from the mains to a transformer and metal rectifier. High-tension supplies for the output stage at 6 000 volts are obtained from a hot-cathode mercury-vapour valve rectifier, and a second supply is similarly derived at 4 500 volts and feeds the third, fourth, and fifth amplifiers. A third supply for the remaining stages is provided from a metal rectifier.

The main controls are all grouped conveniently on one control desk, from which the switching operations are effected by remote control. A sequence starting-switch is provided to prevent damage to the transmitter by the application of power supplies in the wrong sequence, and the modulator is similarly protected by a system of interlocked push-buttons. All electrical apparatus is fully protected by interlocking circuits and water-flow monitoring devices, so that in the event of a failure of any supply the transmitter is automatically shut down and cannot be restarted until the deficiency is remedied.

The provisions for the protection of personnel are such that access cannot be obtained to any of the transmitter units until all dangerous supplies have been switched off and the apparatus earthed. No supply can then be reconnected to the transmitter until the gates of all the units have been closed and locked.

In the centre of the control desk is mounted a cathode-ray oscillograph, including an amplifier and the necessary time-base circuits. Switching arrangements are provided which enable the wave-form of the picture and synchronizing signals to be examined at the output of each stage of the modulator unit, and also the final wave-form at the output of the modulated amplifier.

The total input power from the mains to the vision transmitter is 95 kVA and its output power is 17 kW, corresponding to "full picture white." It is customary to rate the power of television transmitters in terms of peak, since it is not possible to use the normal method of rating in terms of "carrier wave power" as in the case of a sound transmitter, because a television transmitter does not radiate a steady "carrier wave."

(c) Baird Studio Equipment

The transmission of scenes from the Baird studio was effected by two methods: the intermediate film process, which was the first to be employed, and the electron camera, which was introduced subsequently. There was

in addition a further small studio 30 ft. by 12 ft. intended for announcements, talks, and other similar purposes, and from which transmissions were made by the spotlight system. In a further room film transmission was carried out by means of two sets of telecine apparatus. Each of these various sources of programme was regarded as a separate unit, whose output was passed to the main control room adjoining the large studio.

(1) The Intermediate Film Process.

The apparatus for television by this process was housed in an additional sub-control room at the side of the main studio and separated from it by a three-sided window. The scene, illuminated by the studio lighting-equipment described elsewhere, was photographed on to 17·5-mm. film. The film immediately passed in succession through developing, first-washing, fixing, and second-washing tanks. On emerging from the final tank the film was immediately scanned while wet. To effect this the film was passed through an underwater gate upon which was projected a beam of light from a 60-ampere arc. The light, having passed through the film, fell upon a scanning disc running at 6 000 r.p.m. and containing 60 equally-spaced holes arranged on the circumference of a circle. The horizontal scanning component was thus derived from rotation of the disc, while the vertical component was automatically provided by the continuously moving film. The disc was driven by a $\frac{1}{2}$-h.p. 3-phase motor, the disc and motor being enclosed in a chamber and running in a vacuum. This was necessary in order to prevent weaving of the disc due to air resistance, and also to avoid dust entering the small scanning holes. The motor required a supply of alternating current at 100 cycles per sec., which was generated by a separate motor-generator. The latter consisted of three machines in tandem: the 100-cycle alternator, a d.c. motor by means of which the generator and the scanning disc could be slowly run up together, and an a.c. motor which was cut in when the unit was up to speed, thus locking the set in synchronism with the mains.

The light from the scanning disc was arranged to influence a photo-electric cell of the multiplier type, the output of which was passed to a series of amplifiers and thence to the central control room. The line-synchronizing signals were simultaneously generated by the same disc by means of a further series of 60 apertures arranged on a circle within that containing the scanning apertures. These were illuminated by a slit of light, and a photocell situated behind the disc translated these light impulses into synchronizing signals of proper shape. They were then raised in level by an amplifier and passed to the central control room.

The time elapsing between the action in the studio and its appearance on the receiving screen, that is to say, the time required to process and scan the film, was 65 sec. It was, of course, necessary to apply a corresponding delay to the sound, and to effect this it was also recorded on the film by a recording head interposed between the camera and the developer tank. A corresponding reproducing head was fitted into which the film passed after having been scanned in the underwater gate. The film was finally reeled while wet and subsequently transferred to a large drying drum.

A picture monitor was provided in the sub-control room.

(2) Electron Camera.

The studio was equipped with two experimental electron cameras whose associated apparatus was housed in a further adjacently situated sub-control room. These electron cameras were of the type in which a phalanx of electrons emitted from a light-energized photo-cathode was bodily displaced, in the motions of frame and line scan, over an electrode having at its centre a small opening which constituted the scanning aperture. One of the cameras was mounted on a movable run truck, and the other on a tripod. The scanning currents and other supplies for these cameras were all generated in the sub-control room and sent to each camera by a composite cable. The camera outputs were amplified in head amplifiers, and the output passed back along a composite cable to the sub-control room. Inter-camera fading was carried out in this control room, and the single output passed to the central control room.

(3) The Spotlight Studio.

As its name implies, transmissions from this studio employed the spotlight system, in which the artist is kept in almost complete darkness and a spot of light of elemental size is distributed over him by means of a scanning device, the reflected light being picked up by photocells.

A disc scanner was used, running at 6 000 r.p.m. and having four spirals, each of 60 holes. Each spiral was brought into action in turn by means of a further shutter disc revolving at 1 500 r.p.m. The large disc, which was as usual enclosed in an evacuated chamber, was rotated by means of a $\frac{1}{2}$-h.p. 100-cycle 3-phase synchronous motor, deriving its power from a similar motor-generator unit to that described in connection with the intermediate film apparatus. The small disc was driven by a 1/20 h.p. 50-cycle 3-phase motor taking its power from the mains. The light source was a large arc consuming 120 amperes. Owing to the intense heat generated by an arc of this power, the scanning gate was water-cooled.

The reflected light was picked up by four large photocells of the multiplier type, whose positions in the studio were adjustable in order to obtain the correct lighting effects. The outputs of these were applied to an amplifier situated at the side of the studio, whose output was passed to the central control room.

A picture monitor was provided in the spotlight projection room.

(4) The Telecine Equipment.

Two identical sets of telecine equipment were installed. The film was driven under continuous motion by a modified standard film projector, and after illumination by a 60-ampere arc was scanned by a disc unit identical with that already described in the case of the intermediate film apparatus. The light from the disc was picked up by a lens system, and influenced a photocell, again of the multiplier type, whose output was fed to a series of amplifiers. The output from each set of telecine apparatus was then fed to a common control amplifier which was provided with arrangements whereby a rapid change-

over of both vision and sound could be made from one projector to the other. The output was then passed to the central control room. Individual picture monitors were provided for each machine.

(5) The Central Control Room.

The various vision and line-synchronizing inputs from the several sources were first passed to individual termination amplifiers in the central control room. From these they were fed to the main vision control desk, which contained arrangements for changing from one source to another and for monitoring the wave-form.

After further amplification the vision-synchronizing signals were passed to the transmitter via a concentric cable. Frame-synchronizing impulses were generated by apparatus which was common to all of the individual programme sources, comprising a disc rotated at 1 500 r.p.m. and containing one hole which was interposed as usual between a light source and a photocell. The necessary arrangements for mutually adjusting the phase of the various scanners and the central frame-synchronizing signal generator were provided. The frame- and line-synchronizing signals were mixed in an amplifier and passed to further synchronizing amplifiers, the output of which was fed to the transmitter via a further concentric cable.

(6) Sound Equipment.

The sound from the main studio was picked up by three condenser microphones. Associated with these were a control desk and a series of amplifiers in a sound sub-control room situated above the intermediate film sub-control room at the side of the studio. If the intermediate film process was being used, the sound, having been carefully controlled as regards volume, was passed in turn through a recording amplifier, the intermediate film apparatus, and a reproducing amplifier, and thence to the central control room. When the electron camera was used, the sound output was sent, of course, direct to the central control room.

The spotlight studio was also provided with a condenser microphone and its individual amplifying equipment. These two outputs, together with those from the sound heads of the telecinė apparatus, were selected as required from a sound-control desk adjacent to the vision-control desk in the central control room, at which position the main volume to the transmitter was also controlled. The signals then passed through further amplification, and were fed to the transmitter or to a monitoring loud-speaker as required.

The various vision sources were all connected to the central control room by the usual system of cue lights and interconnecting telephones.

(7) Power Supplies.

In the case of the vision apparatus, each stage of amplification had its own individual source of anode voltage, this taking the form of a mains rectifier. The filaments were heated by alternating current via transformers.

The sound-equipment H.T. supplies were derived in the normal manner from rectifiers, and the filaments again were heated from alternating current. The power supply for the arcs of the intermediate film and the two sets of telecinė apparatus were derived from three d.c. generators, each delivering 60 amperes at 110 volts. The power supply for the spotlight arc was derived from a further d.c. generator delivering 200 amperes at 110 volts. All these generators were situated in the transmitter hall.

(d) Baird Vision Transmitter

The Baird transmitter was housed in a hall on the ground floor beneath the Baird studio.

It consisted of five main units: (1) the master oscillator; (2) the intermediate amplifier; (3) the final amplifier; (4) the conditioner; (5) the synchronizing modulator; (6) the vision modulator; (7) the power supplies; and (8) the evacuation and water systems.

It is a feature of this transmitter that the picture and synchronizing signals are never mixed at vision frequency and each modulates a separate part of the radio-frequency chain. The synchronizing signals are applied to the intermediate amplifier, the output of which is raised in level at the final amplifier, and also modulated by the vision signals.

(1) The Master Oscillator.

The radio-frequency signal was originated at a frequency of 1·406 Mc./sec. by means of a crystal master oscillator which was temperature-controlled in an inner and an outer oven. This frequency was then applied to a number of multipliers and amplifiers in cascade, and the unit finally delivered 100 watts at the desired carrier frequency of 45 Mc./sec. It had its own mains-derived power supply.

(2) The Intermediate Amplifier.

This contained a pair of Metropolitan-Vickers demountable tetrodes, either of which could be associated by means of a change-over switch with a set of common radio-frequency circuits, the other tetrode at any time being held as a spare. The intermediate amplifier received the output from the master oscillator and raised it to a level of 1·2 kW at black level. Grid modulation of this amplifier by the synchronizing signals was effected by application of the output of the synchronizing modulator to the control grid of the demountable valve.

(3) The Final Amplifier.

This unit was of similar design to the intermediate amplifier. The final amplifier received the output of the intermediate amplifier and raised it to a level of 17 kW under white-picture conditions. It also received the output of the picture modulator, and grid modulation was again effected at the control grid.

(4) The Conditioner.

This unit was provided to carry out certain necessary conditioning of the demountable valves before they are once more put into service after having been taken down for repair. The process of conditioning consists in applying first of all to the control grid, then to the control and screen grids, and finally to the anode as well, alternating voltages capable of fine regulation. It was in this way possible to drive off the last traces of occluded gas, the

Plate 1

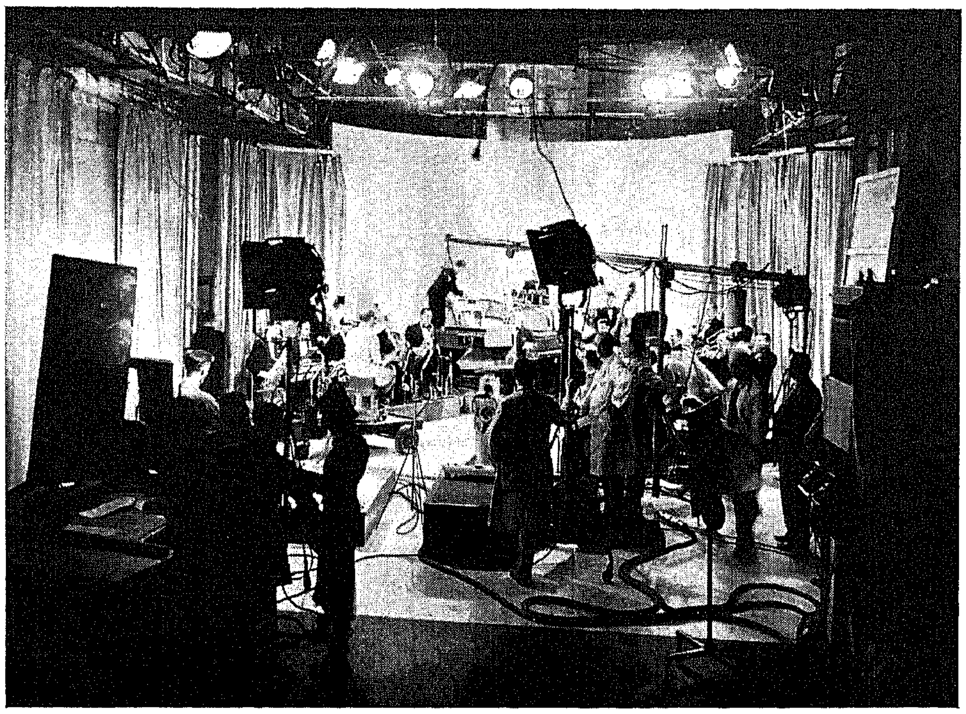

Fig. 8.—Studio scene during rehearsal.

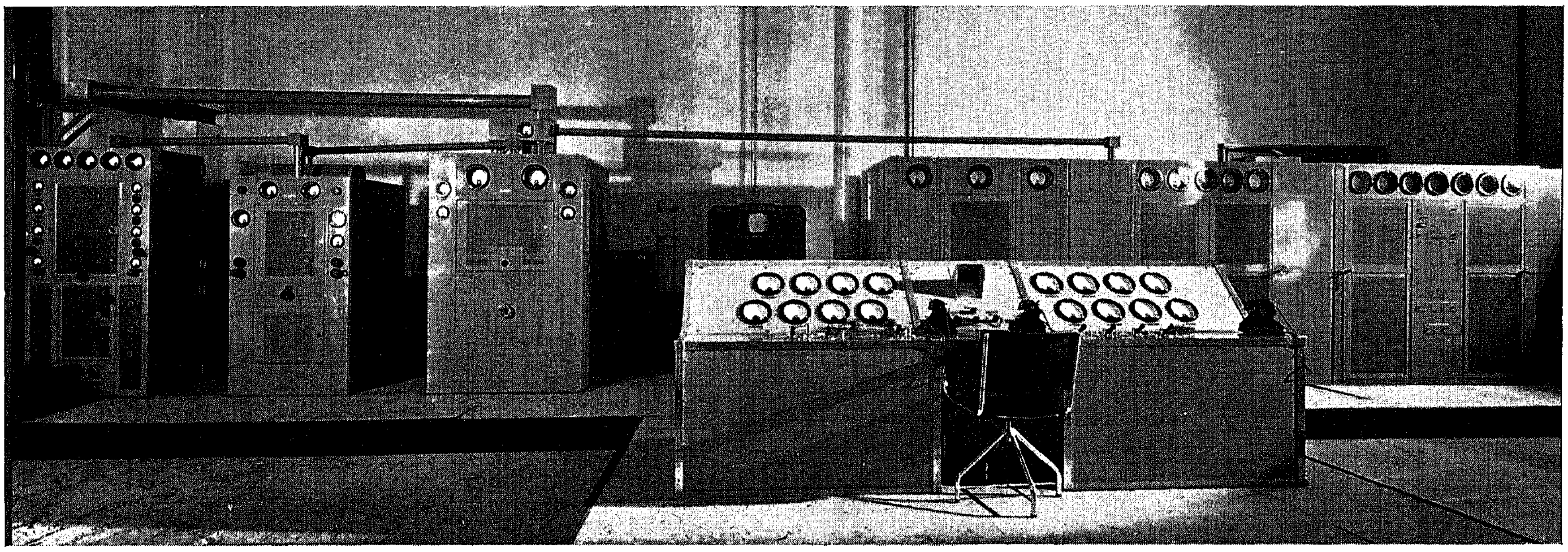

Fig. 10.—Vision transmitter.
Radio apparatus on left; modulator on right; control table in foreground.

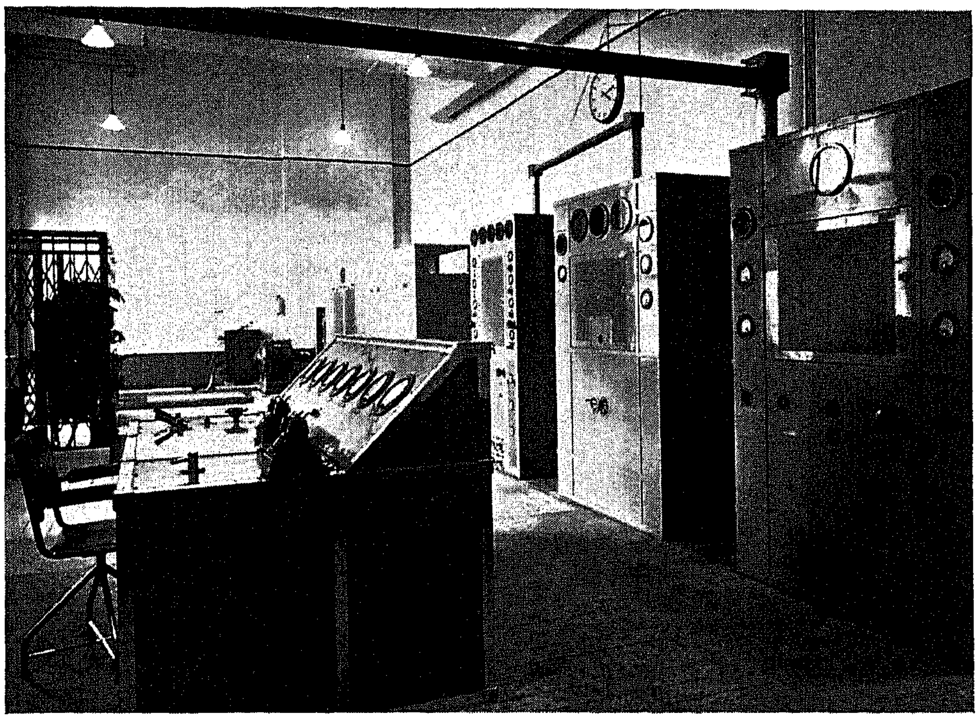

Fig. 11.—Sound transmitter.
Left foreground—Control table.
Centre background—Drive unit and low-power high-frequency stage.
Centre right—Final power amplifier.
Right-hand side—Modulator unit.
Left background—Power switchboard.

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Plate 2

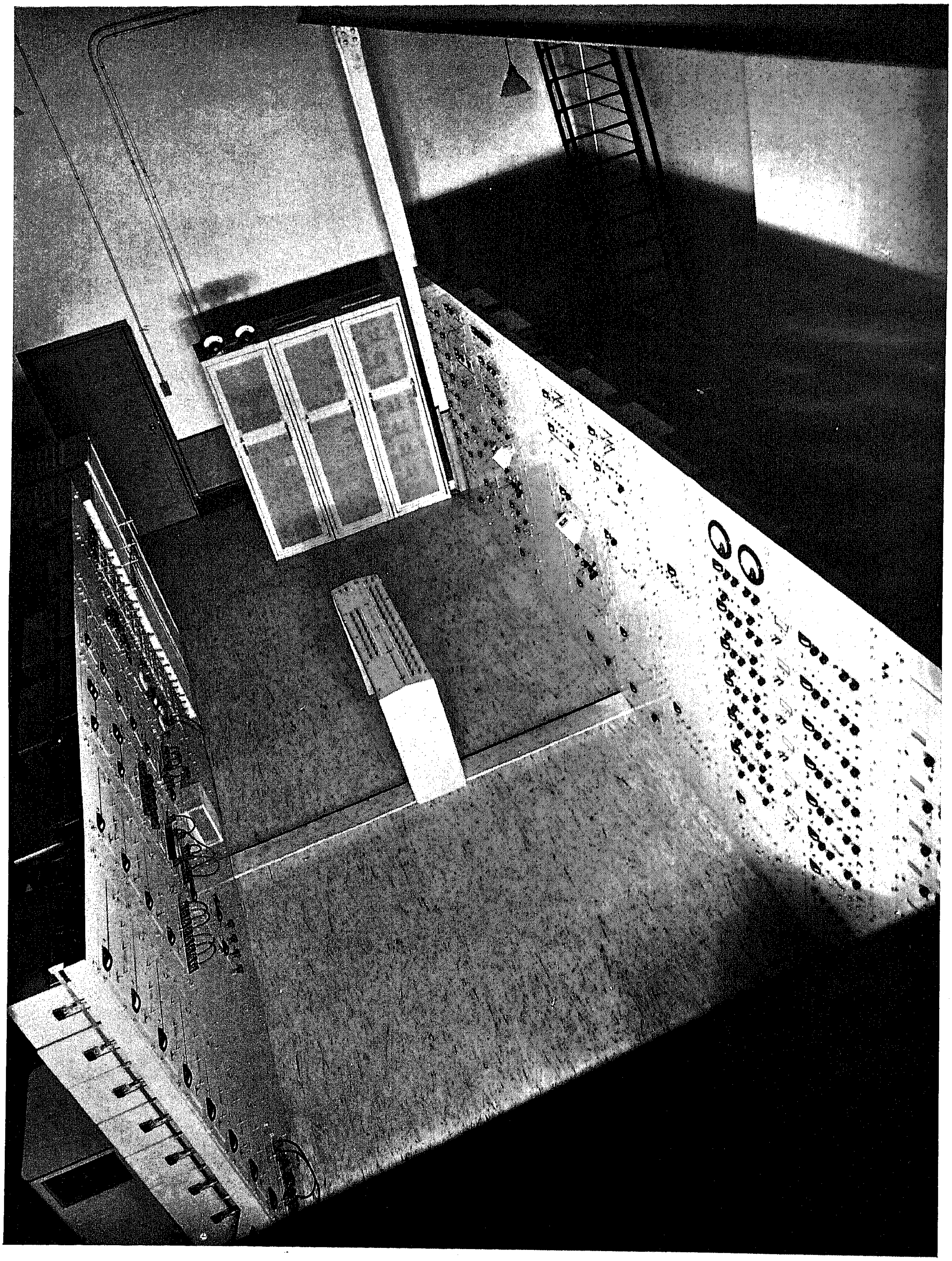

Fig. 9.—Control room of Marconi-E.M.I. system.

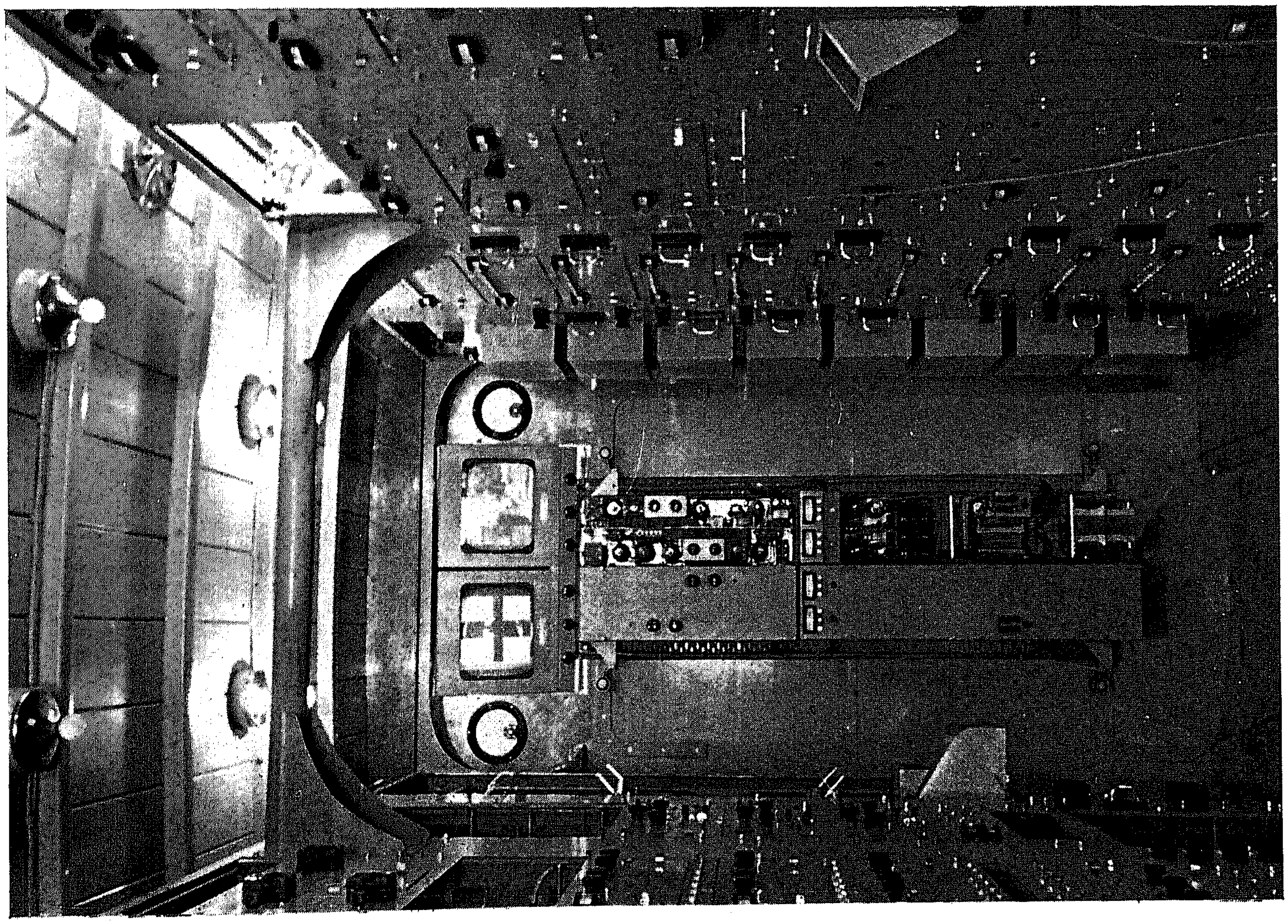

Fig. 12.—Mobile television control-room, showing picture monitors.
At right-hand side—Pulse generating equipment.
At left-hand side—Camera panels.

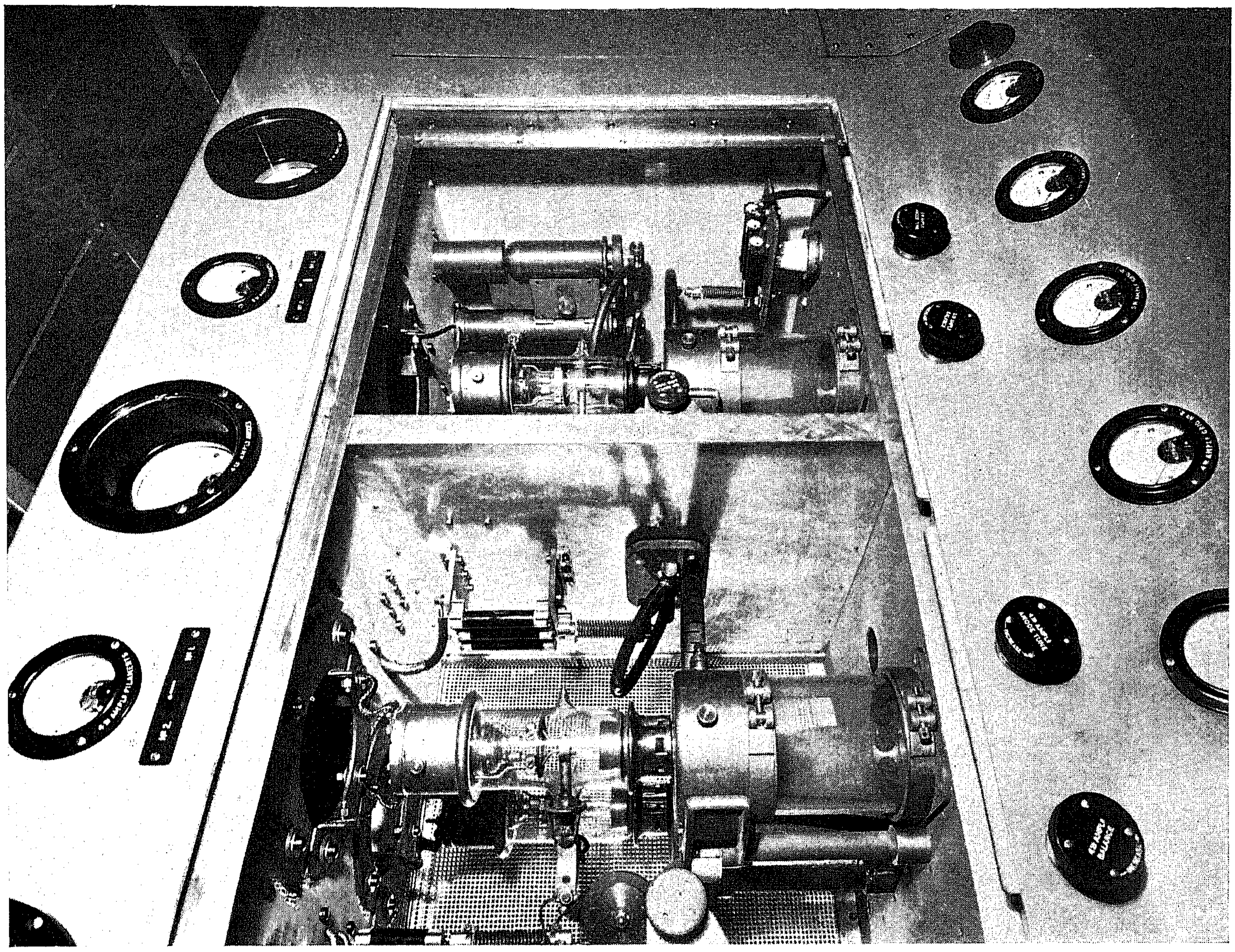

Fig. 14.—Mobile television unit: last two stages of the radio-link transmitter, showing the air-blast-cooled valves.

Plate 4

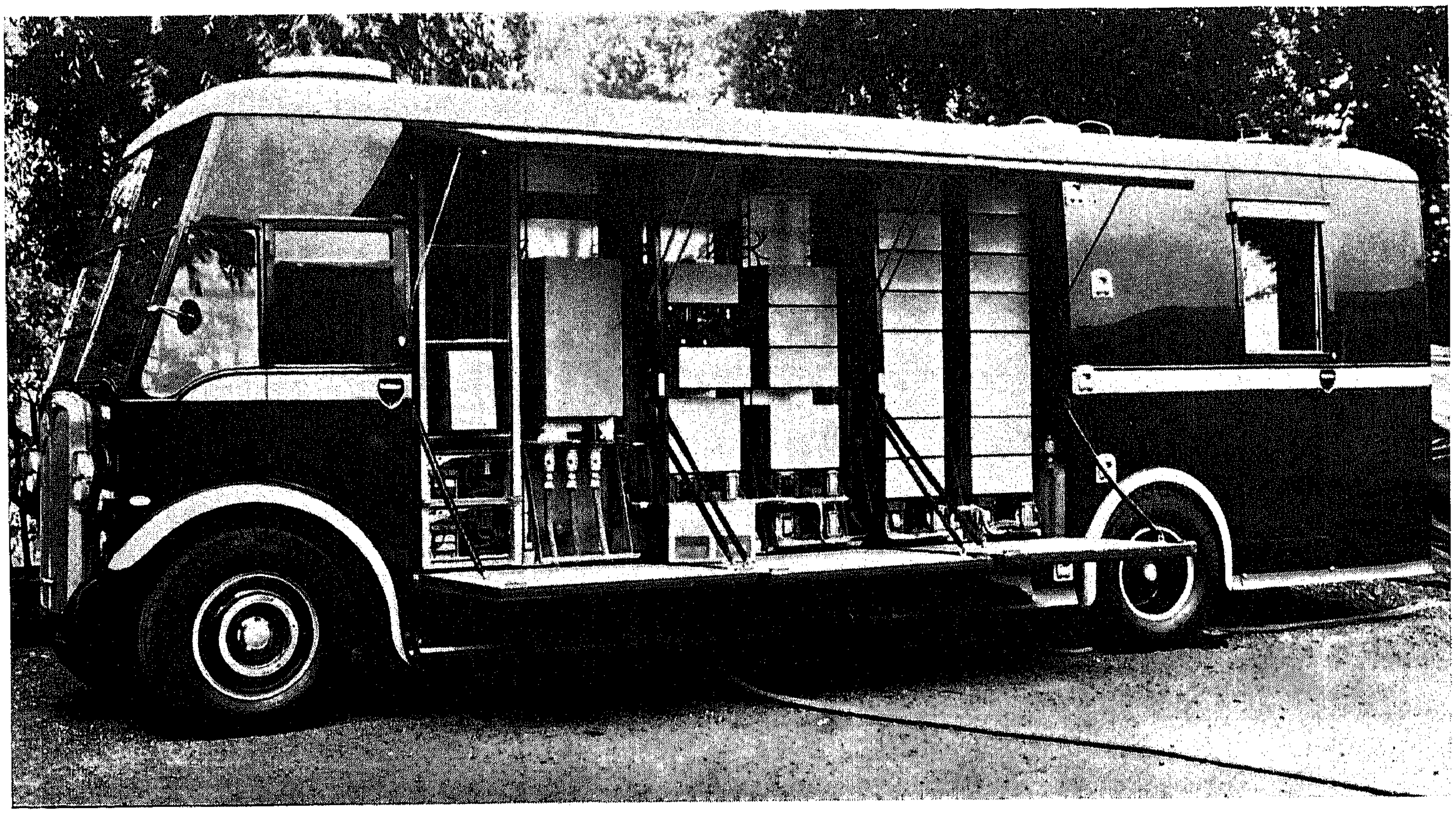

Fig. 13.—Mobile television unit: exterior of control-room vehicle with shutters opened to give access to rear of apparatus.
NOTE.—The camera cables can be seen underneath the vehicle.

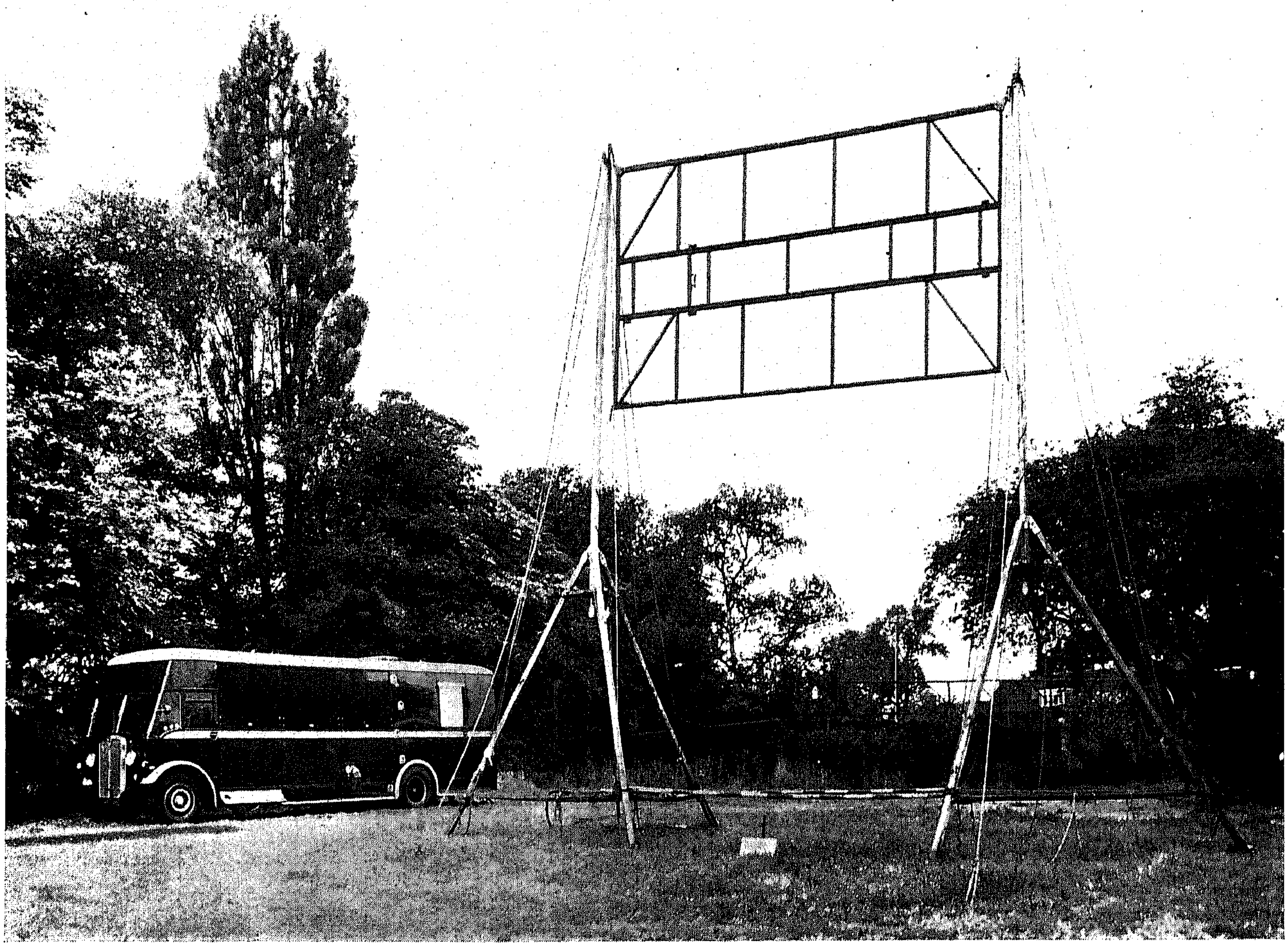

Fig. 15.—Mobile television unit: radio-link transmitter vehicle and portable directional aerial.

presence of which, without this precaution, would lead to the prevalence of frequent overloads upon the valves being returned to service.

(5) The Synchronizing Modulator.

This unit consisted of a 4-stage vision-frequency amplifier delivering a synchronous amplitude of 700 volts to the intermediate amplifier.

(6) The Vision Modulator.

This was a 7-stage vision-frequency amplifier receiving its input from the control room, and delivering picture signals of 1 000 volts amplitude between black and white to the final amplifier.

(7) Power Supplies.

The filament supplies for the final and intermediate amplifiers were each obtained from motor-generators delivering 200 amperes at 25 volts. The anode and screen supplies for the intermediate amplifier were obtained from a motor-generator delivering 14 kW at 7 000 volts for the anode, and 4 kW at 2 000 volts for the screen. The anode and screen supplies of the final amplifier were obtained from a motor-generator delivering 40 kW at 10 000 volts for the anode, and 2 kW at 2 000 volts for the screen. The anode voltage was in this case obtained from two machines connected in series but driven in tandem by a single motor. The modulator power supplies were obtained from rectifiers, and there was, in addition, a floating 2 800-volt 10-ampere-hour battery.

The control of the transmitter, as distinct from the modulator, was centralized at a control desk, on which was mounted an oscillograph for examining the radiated wave-form. Behind this was situated an additional panel for the centralized control of the modulators.

(8) Evacuation and Water Systems.

With each of the demountable valves was associated an evacuation system consisting of two oil condensation pumps in cascade and a rotary pump. This apparatus was entirely automatic, and created and maintained without attention an adequate vacuum in each of the valves. A complete water system was provided for cooling the anodes and heads of the valves and also the oil pumps. These were fully protected by water-flow relays, which would open the appropriate circuits in the event of a water failure.

As usual, complete protection was provided in all the apparatus so that personnel could not have access to dangerous voltages.

(e) Marconi Sound Transmitter

The transmission of sound from either of the two television systems is effected by means of one sound transmitter, which can be fed with the outputs from the control rooms of either system. This is situated on the ground floor of the Palace in a hall between the two vision transmitters, and is illustrated in Fig. 11 (see Plate 1). It normally operates upon a frequency of 41·5 Mc./sec., but is capable of working over a band of frequencies from 35 to 50 Mc./sec. It has an output power of 3 kW at 90 % peak modulation. The total input power from the mains is 78 kVA.

The transmitter is built in four separate units, each unit being housed in a metal cubicle. The carrier frequency is originated by a master oscillator and doubler, the master oscillator working at twice the carrier frequency and ensuring a stability of $\pm$ 1 part in 100 000. This is followed by five high-frequency amplifying stages. The master-oscillator doubler and the first four stages are all contained in one cubicle. A separate cubicle houses the fifth amplifier, at the anodes of which modulation is effected. A third cubicle houses a 3-stage modulator of conventional type. In the final high-frequency stage two C.A.T.9 water-cooled valves in push-pull are used, and in the main modulator stage three C.A.M.3 valves in parallel. The transmitter is designed to give high-quality sound reproduction, and enables advantage to be taken of the greater frequency band available at this short wavelength. The frequency response is flat to within 2 db. between 30 and 10 000 cycles per sec., and, in addition, the distortion factor of this transmitter is very low, the total harmonic content in the output low-frequency signal, expressed as an r.m.s. voltage sum, being 2 % at 90 % modulation.

All the valve filaments except that of the master oscillator are heated by direct current from a motor-generator having an output of 500 amperes at 24 volts. The master oscillator has its own supply from a rectifier.

The main H.T. supply at 6 000 volts (d.c.) for the fourth and fifth amplifiers and the modulator is obtained from a hot-cathode mercury-vapour-type rectifier associated with a transformer and induction regulator and appropriate smoothing circuits. Other auxiliary H.T. and grid-bias supplies are obtained from metal rectifiers. The whole of the H.T. and grid-bias supply equipment is housed in the fourth transmitter cubicle.

A control table is provided at which the essential operating controls are grouped, and the transmitter can be entirely controlled by one operator. The application of power supplies in the correct order is ensured by sequence starting arrangements, and a complete system of interlocks is installed for the protection of the apparatus and of personnel.

In an adjoining room are the necessary water pumps and air blowers for valve cooling.

(f) Mast and Aerial System, and Feeding Arrangements

As previously stated, the transmitting mast is 300 ft. in height, and the ground itself is 306 ft. above sea-level, so that the total height of the mast is 606 ft. above sea-level.

Its design is intimately connected with that of the aerials themselves. Since two separate radiating systems are required, mechanical and electrical considerations both preclude the use of vertical dipoles situated one above the other. It was necessary in order to get uniform radiation in all directions to provide for each radiating system a number of aerials uniformly spaced around the mast. To facilitate this aerial design, therefore, the upper part of the mast structure which carries the aerials has been made octagonal in section and

uniform in diameter. The height of this section is 97 ft. Below this the mast consists of a more orthodox tapering 4-sided structure having a height of 118 ft. 6 in. and base dimensions of 30 ft. by 30 ft. Each of the four corners of the base girders has been taken down through the structure of the building to within a few feet of the ground to obtain a secure anchorage.

The vision signals are radiated from the upper of the two aerial systems. This consists of eight push-pull end-fed dipoles uniformly spaced round the mast. Behind them are eight energized dipole reflectors. Each dipole consists of three wires situated at the corners of a triangle having a 15-in. base, in order to simulate a dipole of considerably greater diameter than that of a wire. All the eight aerial/reflector systems are joined in parallel. A number of concentric networks are provided in order to carry out the necessary transformations, which include rendering the aerial system asymmetrical so that it can be fed by the main feeder, which is of the concentric type, matching the impedance and maintaining a constant impedance over the required radio-frequency band width. In this connection it should be mentioned that the impedance is substantially constant over a band width of 2 Mc./sec. on either side of the carrier. The main feeder has a characteristic impedance of 78·5 ohms and is 5 in. in diameter. Electrical compensation is introduced at intervals in order to minimize the existence of reflected energy.

The sound aerials are situated underneath the vision aerials, and are substantially similar, differing only in their dimensions and in the absence of the elaborate networks necessary to accommodate the wide band-width occupied by the vision signals. They are connected to the transmitter by a feeder identical with that provided for the vision system.

PART 5

OUTSIDE BROADCASTS

(a) Programme Requirements

The televising of national ceremonies and open-air events of sporting and topical interest is perhaps one of the most useful functions which a television service can fulfil. Such events can be divided into two general classes:—

(*a*) Events which can be brought within close proximity to the television station proper but not actually into the studio itself.

(*b*) Events which by their very nature occur at some point remote from the transmitter.

The events classed under (*a*) are such things as demonstrations of horsemanship or golf, and displays of physical culture. These obviously cannot be done in the confines of a studio, but it can be arranged that they take place within a selected area close to the actual television site. Such events are classed as local outside broadcasts, and their televising can be accomplished by an extension of the internal studio facilities. That is to say, cameras can be taken to the scene of operation and directly connected back to the Alexandra Palace control room by means of a length of normal camera cable. In general it may be said that the maximum allowable length of camera cable which can be used without running into serious technical difficulties is approximately 1 000 ft.

Suitable provisions exist at the Alexandra Palace to facilitate such local outside broadcasts. Special cable ducts have been laid under the road flanking the B.B.C. premises, and camera cable can be run to any point in the grounds of the Palace within the limits of 1 000 ft. from the control room.

Similar provisions exist for the direct connection of sound equipment for picking up the sound accompanying the action being televised. Exactly similar technique to that adopted in the studios themselves is thus used for local outside broadcasts, with the exception that artificial lighting is in general unnecessary.

The events classed under (*b*) include such national occasions as a Coronation procession, the Wimbledon tennis tournaments, and the Armistice ceremony. Such events occur at places remote from the main station and it is therefore necessary to employ a different technique from that employed for local outside broadcasts.

In order that events of this type may be included in the television field a mobile television unit has been formed which in effect provides the same facilities for vision and sound as are available at the main station at Alexandra Palace, although of necessity somewhat limited in scope.

The function of this unit is to form a link between the remote outside-broadcast point and the main transmitter, and its requirements are that it shall be capable of conveying both vision and sound back to the main transmitter from any point within a given operating radius.

Every effort has been made to construct the mobile unit in the most transportable form possible, so that the minimum of time is required for moving it to site and setting it to work Rapid mobility is felt to be an essential of a unit of this type, as lacking this quality much of the topicality of the outside-broadcast transmissions will be inevitably lost, and their value thereby greatly reduced.

At present, setting up the equipment for an outside broadcast takes a comparatively long time, perhaps a day or even longer. This is considered to be far too long, and every effort is being made to arrive at a design of all equipment including the smallest accessories such that the process of setting up for transmission can be accomplished in an hour or even less.

Such an achievement clearly involves many difficulties, but it is considered that until it is possible to effect the setting-up in a time of this order, complete flexibility will not have been reached.

(b) Travelling-Studio Equipment

The travelling control room, which, as has been stated, is brought into use in cases where it is required to televise events taking place at points remote from Alexandra Palace, consists of a large motor vehicle, 27 ft. 6 in. long, 7 ft. 6 in. wide, and 10 ft. 8 in. in height, fitted with a closed body of special design.

Inside the vehicle body is mounted all the apparatus required to operate three Emitron cameras and six microphones. The cameras, which when the vehicle is in motion are carried in specially sprung cradles to protect the fragile tubes from the effect of road shocks, are in all respects similar to those used for studio purposes.

When the vehicle reaches the site of the broadcast the

cameras are taken out to appropriate positions, being connected to the apparatus by multi-core cables similar to those used in the studio and each of a total length of 1 000 ft.

Provision is made on the vehicle for carrying 600 ft. of this cable on drums which are lowered through the rear doors of the body by means of a winch mechanism which enables them to be deposited on a hand-truck and so easily transported to the required point. After use, the drums are raised into the vehicle by reversing the operation of the winch.

The apparatus contained in the vehicle consists of all essential portions of the control-room scanning and amplifying equipment described in Part 4(*a*) of the paper, and includes duplicate sets of pulse-generating equipment either of which can be brought into action in the event of failure of the other.

Provision is made for fading from any one camera to another, or for the superimposition of the outputs from two or all three cameras. Two cathode-ray vision monitors are provided, one for the purpose of viewing the transmission actually taking place, and the other for previewing the picture emanating from the camera to which it is next proposed to fade.

The outputs of the six microphones are connected to a six-way fading mixer, so that any microphone or combination of microphones may be chosen as dictated by the requirements of the programme being transmitted. Duplicate speech amplifiers are provided and are equipped with a logarithmic volume indicator and a monitoring loud-speaker. The speech amplifiers are designed to deliver to a Post Office land line a signal of appropriate level for transmission to Alexandra Palace.

The whole of the equipment is made up in the form of flat-fronted panel units mounted in 7-ft. racks which extend down both sides of the body, with a central gangway for the operating personnel, as shown in Fig. 12 (see Plate 3).

The racks themselves are securely bolted together at the top and bottom and at several intermediate points, and the foot-plates of each set are bolted securely to a rigid frame which, in turn, is supported through the medium of resilient indiarubber insulated bushings, upon a series of transverse bearers carried by the chassis frame.

The two sets of racks are linked across the top at four points by strong tubular members heavily braced in two planes by means of welded radius plates.

The whole of the rackwork thus comprises a very rigid structure, carried on rubber-insulated mountings and entirely unconnected with the bodywork of the vehicle, and in consequence of its mass and the method of mounting it is not susceptible to the effect of road shocks.

In practice this method of construction has proved highly successful, and a minimum number of faults due to the disturbance of the equipment by vibration have occurred.

The rear of the racks is not accessible from the interior of the body, and to overcome the resultant difficulty of access to apparatus a particular form of body construction has been adopted, as illustrated in Fig. 13 (see Plate 4). The sides of the body have been made to open over the greater part of the length in the form of flaps. The top half of the bodywork is formed of flaps opening upwards and the lower half of flaps opening downwards. The lower flaps are retained in the horizontal position by means of chains, and they form platforms on which those manipulating the apparatus from the rear may stand at a convenient height. The upper flaps are supported by rods engaging in sockets in the bodywork and serve as a roof to ward off falling rain.

All the equipment is mains-operated, consuming a total of about 5 kW, and is adopted to operate from either single-phase or 3-phase 50-cycle supply mains over the range of voltages normally encountered.

In the absence of supply mains the mobile control room unit may be operated from a petrol-driven generator, details of which are given in the succeeding Section.

The chassis is of the 4-wheel 45-h.p. 6-cylinder petrol-driven type, and in the fully loaded condition weighs approximately 9 tons.

(c) Travelling Vision-Transmitter and Power Unit

The preceding Section described the mobile control-room apparatus for generating and monitoring vision and sound at an outside-broadcast point remote from Alexandra Palace. Both sound and vision must clearly be conveyed to Alexandra Palace in some manner so that they may be broadcast from the normal aerials to be received in the ordinary manner on viewers' receiving sets.

Conveying the sound signals to Alexandra Palace presents no difficulties, as use can be made of Post Office line circuits in the usual manner, but the vision signals present a serious problem. At the present moment it is not possible successfully to transmit television signals through the medium of ordinary land-line circuits of appreciable length, and while special television circuits exist, as will be described in a later section, their scope is limited at present, and many events of interest take place in localities far removed from these special circuits.

In circumstances such as these, other means for linking the mobile control room with Alexandra Palace must be adopted, and to this end a second mobile unit comprising an ultra-short-wave radio transmitter has been constructed.

This unit is mounted in a second vehicle of precisely similar construction to that used for the mobile control room, as previously described.

The transmitter is built into two sheet-steel cubicles, which are disposed either side of the centre line of the vehicle body and are carried by means of resilient bushings upon transverse bearers affixed to the main chassis members of the vehicle.

The transmitter is designed to operate at a frequency in the region of 64 Mc./sec. and delivers to the aerial a power of 1 000 watts at peak picture-white modulation.

The radio-frequency portion of the installation consists of a valve master oscillator operating at 32 Mc./sec., having a frequency stability of 1 part in 5 000. This is followed by one doubler stage, and five stages of neutralized push-pull radio-frequency amplification, modulation being by grid control on the final stage, depicted in Fig. 14 (see Plate 3).

All valves are of the air-cooled type throughout, and in the case of the final and penultimate stages consist of small water-cooled valves designed for working at these frequencies, modified for air cooling by having intimately

affixed to their anodes a type of copper honeycomb, through the cells of which air is rapidly forced. Heat generated by the dissipation of energy in the valves is thus removed, without the use of cooling water, the presence of which would be inconvenient in a mobile vehicle.

The modulating equipment is designed on the same lines as that installed as part of the Alexandra Palace vision transmitter, but of course on a reduced scale, air-cooled valves being used throughout. The whole equipment is designed to pass, with a minimum of loss at the high frequencies, the wide frequency band required, and to transmit a signal having the same general form as that radiated from the main vision transmitter.

The output of the transmitter is adapted to feed the aerial either through a balanced open-wire feeder of about 500 ohms characteristic impedance, or, alternatively, by means of a coaxial high-frequency cable of 110 ohms characteristic impedance.

The first type of aerial used consisted of a two-stacked balanced series phase array adapted to emit a vertically polarized wave and having marked directional properties. This aerial was constructed on a Jarrahwood frame, approximately 18 ft. long by 12 ft. high, which was slung between two 30-ft. transportable wooden masts with tripod bases, both the masts and the aerial frame being capable of being dismantled into component parts of such size as to make transport possible. The vehicle and masts, as set up at the All-England Tennis Club at Wimbledon, are shown in Fig. 15 (see Plate 4).

It will be noted that in the interests of portability the height of the transmitting aerial was kept low, an action which was held to be justifiable on the following grounds.

Evidence showed that good-reception conditions could be obtained using a high transmitting aerial in conjunction with a comparatively low receiving aerial, and it is generally conceded that the converse must in theory apply. Consequently it was felt that if a very high aerial could be installed at the receiving point, a comparatively low aerial could be used with the transmitter, with manifest advantages from the point of view of rapid erection and dismantling. An aerial, details of which are given in a later Section of the paper, was therefore installed at the top of the Alexandra Palace transmitting mast for purposes of reception.

It must be understood that a very limited time was available for experimental work on these aerials, as it was necessary to provide some form of equipment in order that the apparatus should be available for certain imminent outside broadcasts, notably the Coronation procession and the tennis championships at Wimbledon.

In practice, rather variable results were obtained with the low series phase aerial, as it was found that from some outside broadcast sites a good signal strength giving a satisfactory signal/noise ratio was received at Alexandra Palace, whereas from others the results were very poor. For example, from Wimbledon a field strength of approximately 2 mV/m. was obtained, whereas from Hatfield Aerodrome, whence an attempt was made to relay the start of the King's Cup Air Race, a very low signal strength of the order 250 μV per metre only was obtained, which gave an insufficiently good ratio of signal to noise to maintain synchronism of the picture. The actual length of the radio-link path was $11\frac{1}{2}$ miles in the case of Wimbledon, and 13 miles in the case of Hatfield, and there clearly is not sufficient difference in these distances to account for the widely divergent field strengths obtained.

Some attempt was made to determine the factor influencing this divergence, and inspection of the topographical features of the intervening country revealed that in the case of Wimbledon, while the actual height of the site above sea-level was not great, being of the order of 100 ft., the transmitting aerial stood effectively on the summit of the highest ground in the district and a very marked falling-away of the ground occurred immediately, there being no high ground in the path of the wave for a number of miles.

In the case of the Hatfield site, on the other hand, the transmitting aerial stood on fairly level ground, there being no falling-away in the direction of the receiving point. There was in fact a certain amount of rather higher ground between the transmitter and the receiver, fairly close to the transmitting aerial, and it could only be assumed that this had the effect of introducing local attenuation, which resulted in the weak signal strength to which previous reference has been made. It would therefore appear that one of the most important influences on the performance of a short-wave transmitting station of this type with a low aerial lies in the nature of the immediately surrounding country. That is to say, if the transmitting aerial stands at the top of a local eminence with the ground falling away in the direction of the receiving point, and no high ground exists in the path of the wave for a number of miles, the signal strength obtained at the receiving point is likely to be good, even though there is some high ground between the transmitting and receiving aerials to the exclusion of the possibility of an optical path, provided that the obstruction is at some considerable distance from the transmitter. On the other hand, if an appreciable tract of ground, higher than or even level with that on which the transmitting aerial stands, exists in the vicinity of the transmitting aerial and between it and the receiver, very severe local attenuation appears to occur.

At present no quantitative data are available regarding this point, but field-strength surveys tracing the attenuation of the wave under various conditions will be made as soon as equipment for this purpose is completed.

It is well known that the height of either the transmitting or the receiving aerial has a very marked influence upon the received signal; consequently, after the difficulties experienced at Hatfield, attention was turned to the possibility of using a higher transmitting aerial in order to obtain a better ratio of signal to noise in the received signal. At the Pinewood film studios, Buckinghamshire, whence television broadcasts depicting the making of a film were carried out, it was found that raising the series phase array some 50 ft. on to the roof of the studio gave a gain of some 10 db. in the received signal compared with that obtained with the aerial at ground-level.

Practical experience to date therefore indicated that the use of a higher transmitting aerial was eminently desirable, and as the series phase array mounted on a somewhat bulky frame was clearly not a very convenient

form of aerial for mounting at greater heights, attention was turned to other and simpler forms of aerial array which should be lighter in weight and more easily supported on a higher mast.

Comparisons made between the series phase array and a single vertical centre-fed dipole aerial at the same height indicated that the gain due to the former was approximately 6 db. The addition of an unfed vertical dipole reflector resulted in a gain of 2 db., so that for practical purposes it may be said that the dipole with reflector gives approximately 4 db. less signal strength than the series phase array, if erected at the same height, but owing to the very much lighter nature of the former it is possible to erect it at a greater height with a corresponding increase in received field strength. In later outside broadcasts, therefore, a single dipole radiator with reflector has been used, erected on wooden poles fastened to existing buildings at heights from 80 ft. to 100 ft. above ground-level as found to be practicable, and giving received field strengths estimated to be from 12 to 15 db. above that given by the series phase array mounted on 30-ft. masts. Owing to pressure of time it was not possible to obtain exact quantitative results in all cases.

The raising of the transmitting aerial to these greater heights has brought in its train certain difficulties concerned with the feeding of the aerial. For example, the use of long open-wire feeders is extremely inconvenient, as they are fragile and difficult to transport and are also liable to become twisted unless considerable pains are taken with their erection. Further, if they come into close proximity with metal objects, such as roofs or drain pipes, serious losses are liable to occur.

It is clear that coaxial types of feeders if sufficiently robust and flexible represent a more convenient method of feeding the aerial, provided that the loss introduced thereby is not excessive. A type of lead-covered high-frequency feeder having spaced internal insulation of low power factor, and a characteristic impedance of 110 ohms, was used for several of the later outside broadcasts and gave a very good performance from the electrical point of view, in that the losses for the length required were extremely small. This feeder, however, was originally designed for permanent installation and not for continuous handling, and when used for the purpose described it was found to be too fragile to be really practicable. In consequence a high-frequency cable has been developed of similar design but having a copper-tape armouring in place of the lead covering, and experimental lengths which have been tested show considerable promise from the point of view of both electrical suitability and mechanical strength, while being much lighter than the lead-covered type. It may therefore be said that the problem of feeding high portable aerials has been largely overcome, as the new type of feeder can be treated as a flexible cable and repeatedly wound up on a drum without damage.

The question of a suitable support for a higher aerial has received a good deal of attention, and numerous proposals have been considered. The practice of lashing wooden poles to existing buildings is clearly of the nature of a makeshift, and it occupies far too much time to be admissible in a transportable equipment where rapidity of setting up is regarded as of cardinal importance.

The use of portable masts does not offer an entirely satisfactory solution to the problem, as wooden masts of sufficient height to be effective are largely impracticable, on the grounds of the time taken for their erection and difficulties which are frequently encountered as far as space is concerned. Steel portable masts are equally inconvenient, with the added disadvantages of greater weight and the bad influence which a metal mast with its stay wires is likely to have upon the radiating properties of the aerial system.

Attention was therefore turned to the fireman's ladder, a highly specialized and well-developed form of structure which is ideally suited to the purpose in view, in that it combines extreme portability with ease and rapidity of erection.

Designs have therefore been drawn up foi a lightened form of wooden extensible ladder carried on a motor chassis which will form a rigid base for the aerial mast when the latter is erected.

The ladder will be pivoted on a rigid frame at the rear of the chassis, so that when lowered it will lie along the roof of the closed body with which the vehicle will be fitted. Erection will be accomplished by means of power derived from the engine, and it is anticipated that the process of raising or lowering will occupy only 2 or 3 minutes.

The mast vehicle will also serve the dual purpose of a tender for the mobile control room and transmitter vehicles, carrying all necessary accessories such as drums of additional cable, spare parts, and the like.

Mobile Power Unit.

A third vehicle of similar construction to those containing the mobile control and transmitting apparatus houses a petrol-driven engine-generator set capable of supplying power for both the other units, thus making the mobile outside-broadcast equipment independent of supply mains in places where these are not available or are unsuitable.

The engine is of the 6-cylinder omnibus-propulsion type and develops 120 b.h.p. at 2 200 r.p.m. It is direct-coupled to a 3-phase 415-volt 50-cycle alternator operated at 1 000 r.p.m., at which speed the engine is adjusted to develop 50/55 b.h p., giving a maximum electrical output of approximately 30 kW.

The engine and alternator are carried on a fabricated bedplate which is rigidly secured to the main members of the chassis. The engine is covered by a bonnet at the front end of which is mounted a radiator for cooling purposes, through which a fan draws air from the interior of the body. The heated air is ejected through an aperture in the floor boards of the vehicle and, in consequence, the interior of the body is well ventilated and kept free from noxious vapours.

The engine is provided with a centrifugal governor operating on the throttle valve of the carburettor, designed to give an accuracy of speed control under widely varying load conditions of $\pm 2\frac{1}{2}$ %. Under the comparatively steady-load condition representing normal working, the speed remains sensibly constant. The output voltage of the alternator is controlled by an automatic voltage regulator of the carbon-pile type, the chief function of which is to protect the apparatus against

dangerous voltage surges during the process of switching load on and off.

Owing to the fact that the engine is liberally rated and thus operated well below its maximum output power and speed, commendably steady and sweet running is obtained over long periods with a minimum of attention and without vibration and trouble.

(d) Radio-Link Receiver at Alexandra Palace

The receiving aerial is mounted on the extreme top of the Alexandra Palace mast and is designed for the reception of vertically-polarized waves, taking the form of an electrically cylindrical dipole mechanically simulated by a number of wires arranged in a circle. It is connected through a series of transformations of similar form to those used on the vision aerial, to a lead-covered air-spaced paper-insulated coaxial feeder of about $\frac{3}{4}$ in. diameter, terminating at the receiver adjacent to the control room.

The receiving aerial is, of course, tuned to 64 Mc./sec. and it so happens that, as a result of transformations and the attenuation of the feeder, the signal voltage produced across the terminals of the receiver is approximately equal to the field strength of the signal incoming to the aerial.

An unwanted signal of the order of 10 volts (r.m.s.) total at the terminals of the receiver is induced into the receiving aerial from the local sound and vision aerials, and high-pass filter circuits are incorporated giving a discrimination of some 70 db. in favour of the wanted signal without the introduction of significant phase distortion.

Assuming a field strength of 2 mV/m. from the distant station, it will be seen that the wanted signal and local interference appear sensibly equal at the input to the first stage of the receiver.

The remaining discrimination between wanted and unwanted is achieved by the use of a superheterodyne receiver with a first detector having linear characteristics over a wide range, so as to preclude the possibility of cross-modulation, and intermediate-frequency stages having suitable band-pass characteristics.

The receiver takes the form of a 10-stage superheterodyne using an intermediate frequency of 7 Mc./sec. and is provided with automatic volume control and indicating instruments, including an oscilloscope for observing the received signal wave-form. No amplification is used at the original frequency (prior to the frequency changer), but three stages of vision-frequency amplification are introduced after the second detector, arrangements being made that the output shall contain the full d.c. component of the signal.

The output is thus in the usual form of vision + synchronizing signals, which is applied to the vision transmitter without the introduction of any further impulses or signals. It is taken to a suitable point in the control room, where, by means of relays, the input to the vision transmitter can be rapidly changed over from the output of the local studio apparatus to the output of the receiver. A rapid change-over is essential, as it is necessary to change from locally-generated synchronizing signals to those coming by radio from the distant point, and a complete cessation of synchronizing impulses to the transmitter would cause serious overloads if maintained for an appreciable space of time.

(e) Television Transmission over Cables

Attention in this country, as well as in others, has for some time been directed towards the transmission of television signals through line circuits, not only for the purposes of linking up outside broadcast transmission but also to permit ultimately of a simultaneous broadcast of a television programme from a number of widely-separated radio stations. A detailed examination of results so far obtained falls rather outside the scope of the paper, but it is felt that some brief reference to the broad lines along which investigations are proceeding would not be out of place.

In general, the types of circuits under consideration have fallen into three main categories:—

(*a*) Unbalanced coaxial cables designed for multi-channel telephony and/or television.
(*b*) Balanced-pair low-capacitance cables primarily designed for television.
(*c*) Normal telephone circuits.

As regards (*a*), experiments are in progress by the Post Office Engineering Department to determine the requisite conditions for satisfactory operation on a long route of cable of this type, with particular reference to the coaxial circuits already existing between London, Birmingham, and Manchester, intended for multi-channel telephony.

As regards (*b*), a network of this type of cable, supplied by the Marconi-E.M.I. Television Co. to the Post Office, has been installed round the centre of London, following the route depicted in Fig. 16. As will be seen, this route embraces numerous points of interest, including the site of many national functions as well as places of entertainment such as theatres, etc., and proceeds via Broadcasting House to Alexandra Palace. Tapping points are provided at frequent intervals along the whole cable route.

All signals originating on this circuit are led into a repeater station at Broadcasting House, where equalization and phase correction take place, after which the signals are amplified and directed to Alexandra Palace, where further equalization and amplification is necessary before they are applied to the vision transmitter.

As regards (*c*), the British Broadcasting Corporation has carried out certain experiments on short lengths of ordinary telephone circuit with the particular object of using such circuits as extensions to the balanced television cable where distances of 1 or 2 miles only are involved. The use of such spur circuits would be invaluable in cases where the site of an outside broadcast is situated a mile or so from the main television-cable route.

Preliminary investigations on these lines have been made to determine the suitability of ordinary dry-core paper-insulated cables for the transmission of frequencies in the vision range. The primary constants vary, not only with the physical dimensions of the pair concerned, but also with its disposition relative to the other conductors in the cable. The iterative impedances of pairs measured vary between 75 and 140 ohms.

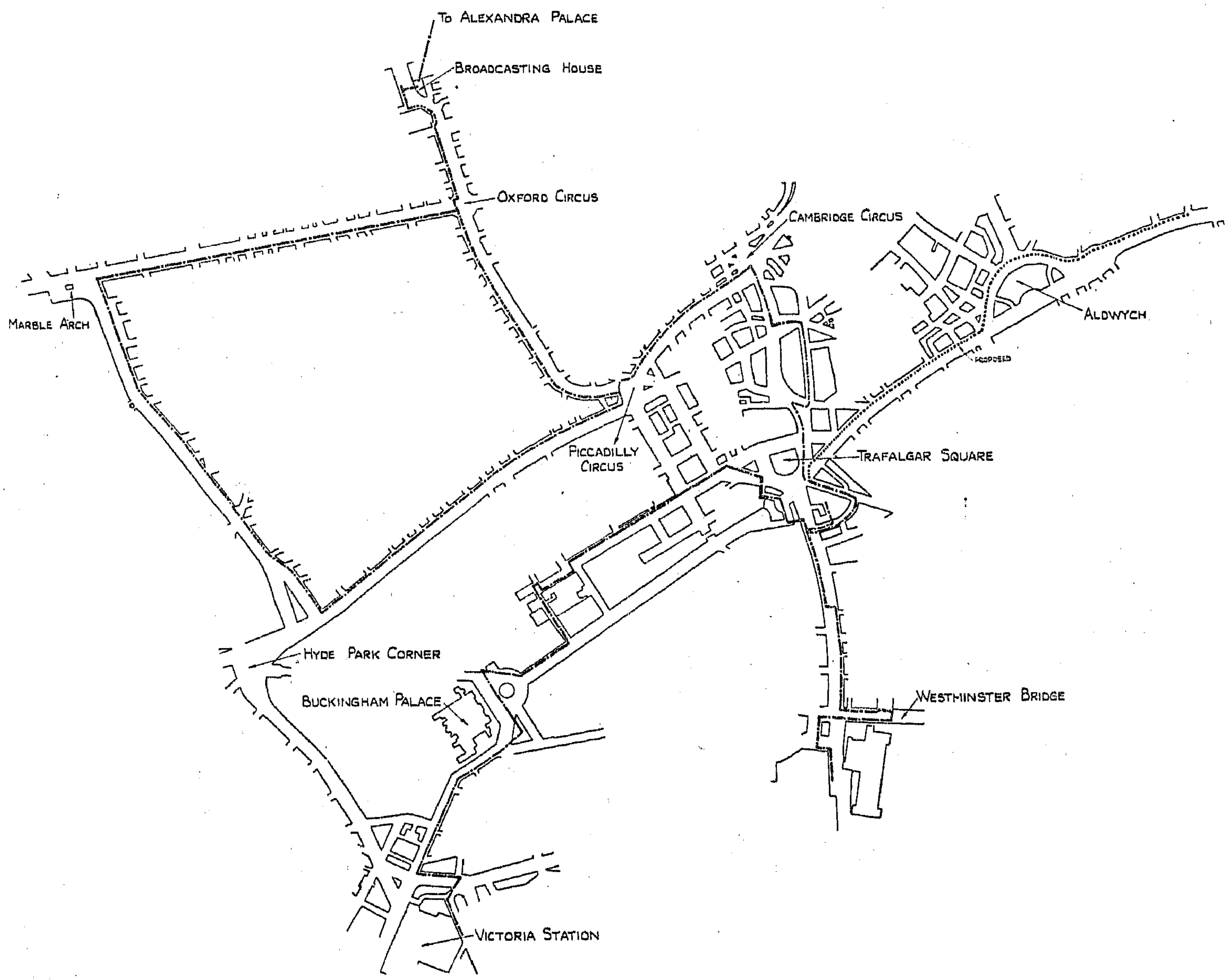

Fig. 16.—Balanced television cable route.

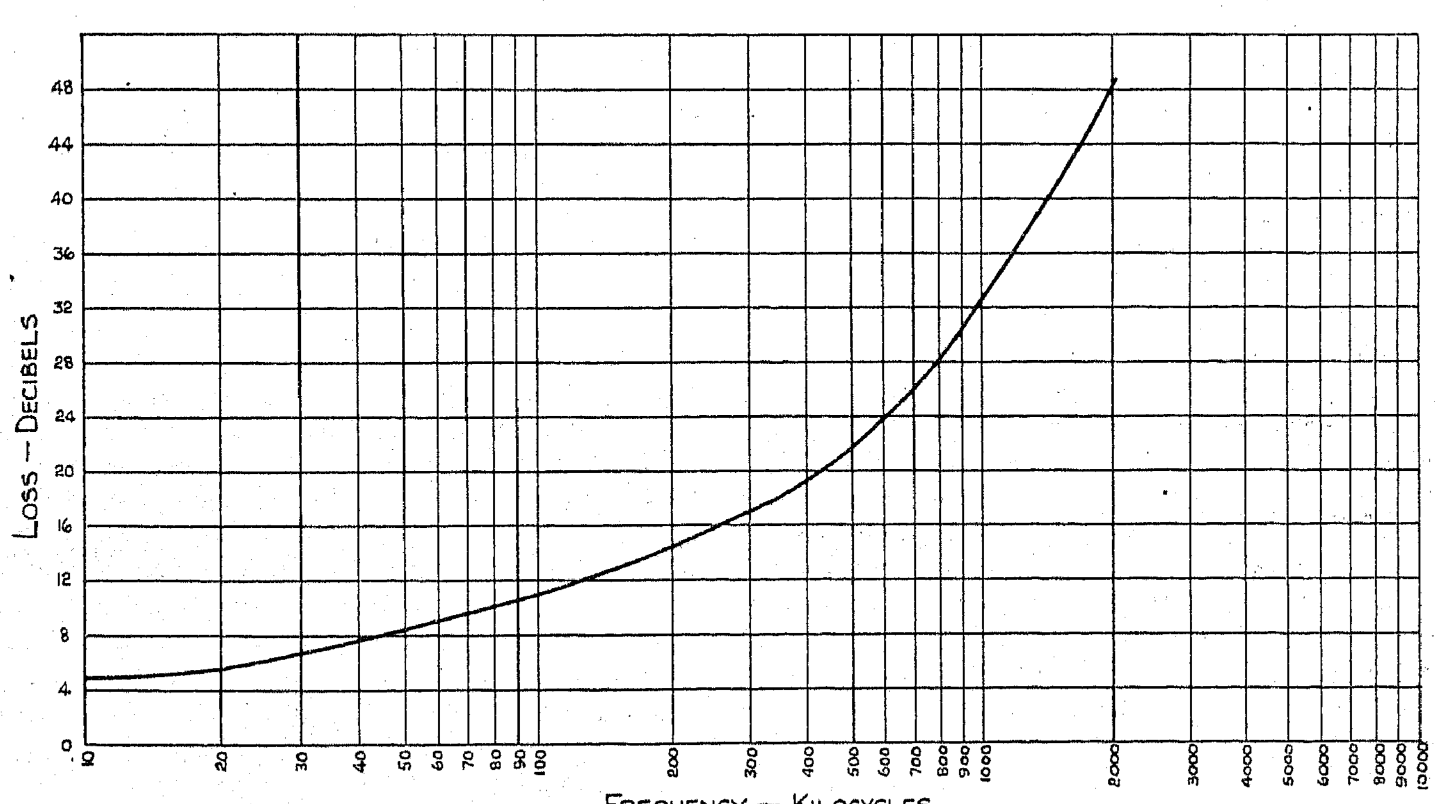

Fig. 17.—Insertion loss characteristic between 140-ohm resistances of 1·2 miles of 10-lb. paper-insulated cable.

Fig. 17 shows the insertion loss/frequency characteristic of 1·2 miles of 10-lb. twisted pair in a particular cable, measured between 140 ohms impedance. The shape of the characteristic is such that it can be equalized quite easily to within ± 1 db. over the whole frequency range by simple constant-resistance networks.

Measurements made on short lengths of cable indicate that where small-gauge conductors are concerned the high-frequency value of inductance is reached below 200 kc./sec., which means that at frequencies above this value the frequency/phase characteristic is linear, apart from a secondary effect of attenuation which becomes apparent at the higher frequencies. For the limiting lengths of circuit contemplated, it is possible to obtain the phase characteristic up to 200 kc./sec. by open-circuit and short-circuit impedance measurements. The phase distortion introduced by the attenuation-correcting networks has to be compensated, but as the required correction can be easily calculated this presents no difficulty.

A problem which requires special attention is the connection of the balanced circuit to an unbalanced amplifier at the low-level end of the circuit, as the longitudinal currents normally present in the cable pair must be much attenuated before they are effective in the unbalanced input of the amplifier. A specially-designed shielded repeating coil was included in a circuit of suitable constants, and was found to transmit frequencies in the range 50 cycles per sec. to 2·2 Mc./sec. with small attenuation and phase distortion.

With this arrangement of terminal apparatus, the noise level on the 1·2-mile section of cable referred to in Fig. 17 was better than 50 db. below the equalized signal. This method of transmission has not yet been used, and experimental work is still proceeding.

PART 6

PERFORMANCE OF THE STATION

(a) Field-Strength Measurements

A series of field-strength measurements have been taken on the television transmitters at Alexandra Palace, using for the most part the sound transmitter operating on 41·5 Mc/sec.

It has not been practicable to examine the field from the vision transmitter with the same detail as that of the sound transmitter, owing to the nature of its modulation, but comparison measurements of the relative value of field strength of the two transmitters have been made at numerous points, and it has been found that the average field strength due to the vision transmitter is 85 % of the sound-transmitter intensity.

This result is to be expected, as the vision transmitter radiated power varies from 17 kW at peak white to about 1·5 kW at black, with little radiation during synchronizing signals. The average radiated power is thus comparable with that of the sound transmitter which operates with a carrier-wave power of 3 kW.

Fig. 18 is a contour map of the field strength at ground level over the region within 25 miles of the transmitter.

The apparatus used for determination of the field strength was mounted in a vehicle, and consisted of a field-strength measuring receiver designed on the following lines.

The receiver took the form of a superheterodyne, using an intermediate frequency of 500 kc./sec., in which the input terminals were connected directly to the frequency-changer unit through an aperiodic coupling.

The efficiency of the frequency changer was shown to be independent of frequency, and consequently the received ultra-short wave signal could be measured by direct comparison with a locally generated medium-wave signal, the local-oscillator frequency being altered as required.

The efficiency of the aerial system at the required wavelength was determined by means of a loop radiator giving a calculable field, and once this had been evaluated it remained unchanged, provided that the operating wavelength was not altered.

In operation the receiver was set up and adjusted for the incoming ultra-short-wave signal, and the deflection produced by it on a galvanometer was noted. The medium-wave local-signal generator was then switched on and the frequency of the receiver local oscillator adjusted to an appropriate value. The voltage injected by the local-signal generator was then adjusted until the same reading on the galvanometer was obtained, and the voltage so injected determined by means of a thermal milliameter and calibrated attenuator. The value of voltage so obtained was then equal to the voltage due to the distant ultra-short-wave signal, and by applying a suitable factor (previously determined) for the aerial system, the actual field strength of the distant signal could be evaluated.

(b) Propagation over Long Distances

Field-strength measurements have been made at distances from 50 to 800 km. in an approximately straight line in a northerly direction to determine the behaviour of ultra-short-wave signals beyond the normal service area.

Fig. 19 shows the results, plotted in terms of *Ed* against distance, for day and night conditions.

It will be noted that these results appear to establish quite clearly the existence of a weak sky-wave at distances beyond about 150 km. under both day and night conditions, and this fact will have to be taken into account from the interference point of view in the consideration of the establishment of further stations.

(c) Reports of Reception, and Interference Problems

Reports of reception of the Alexandra Palace television transmissions have in general been encouraging.

The range of the station was originally estimated to be approximately 25 miles, but in practice it has proved to be better than the value forecast, in that it is fairly safe to say that good reception can be obtained up to about 35 miles, except in cases where exceptionally bad interference is encountered.

Reports of vision reception have been received from places as far distant as Brighton, Southend, Cambridge, and Bedford, which are situated at distances of from 40 to 60 miles from the Alexandra Palace. Reception in these cases has been carried out under exceptionally favourable conditions, such as the receiving station being situated on high ground and some distance from sources of interference; consequently, these results cannot be regarded as entirely normal.

Reports of reception from even greater distances have been obtained, including such places as Rugby, which is approximately 70 miles from Alexandra Palace, and even from a place in the vicinity of Manchester which is situated about 190 miles from Alexandra Palace.

In the case of the former, reception conditions were quite exceptional, the receiver being situated at the top of a 110-ft. concrete water tower standing in the middle of fields at a considerable distance from all roads. In the latter case it must be assumed that reception was due to reflection phenomena.

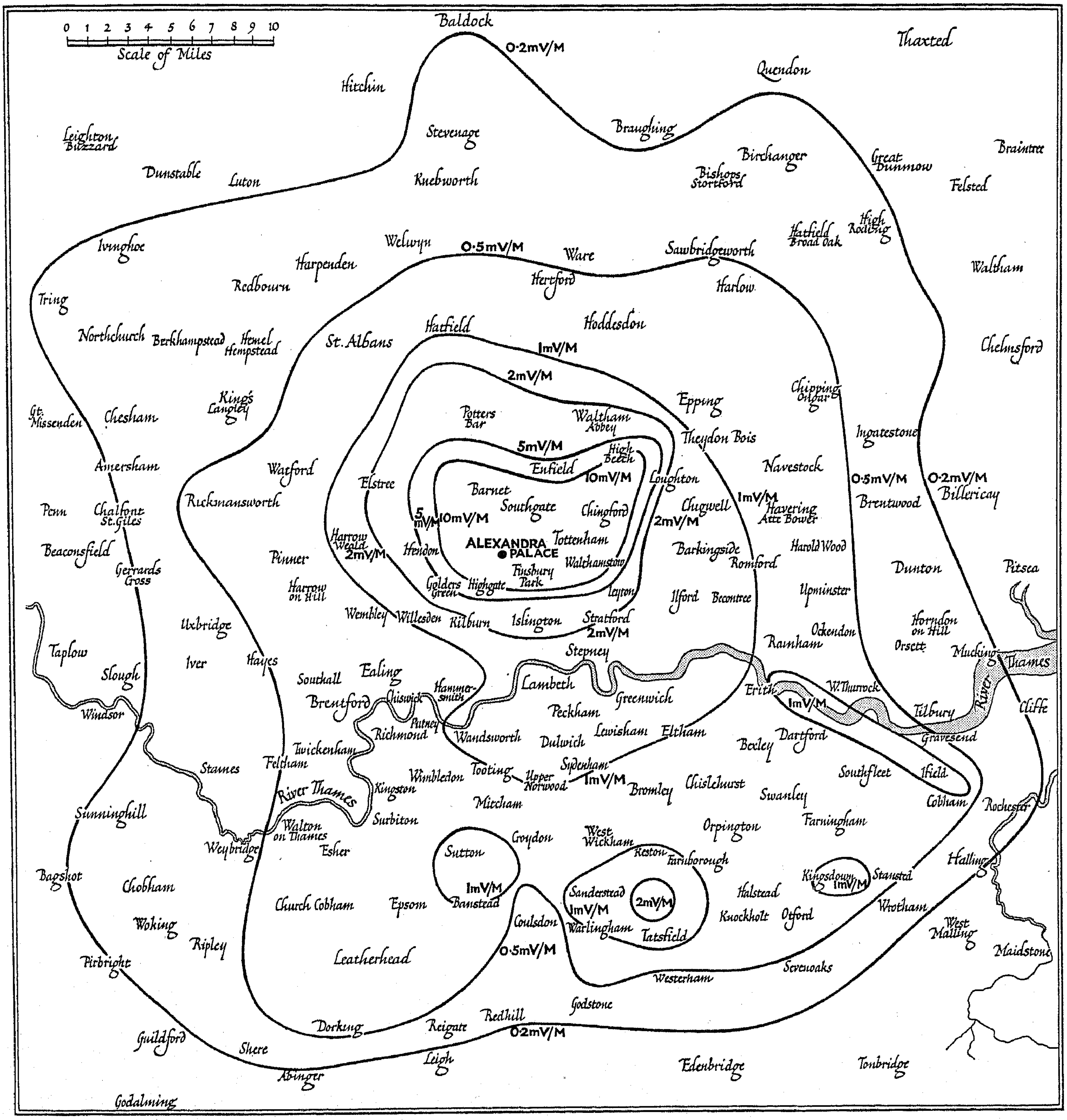

Fig. 18.—Field-strength map of London Television Station.

The whole question of distant reception is, as usual, bound up with conditions of interference, and there seems little doubt that the limiting condition for reception lies in the ratio between the signal and the noise due to sources of interference extraneous to the receiver. It appears that in normal circumstances the condition is not reached where valve and other noises in the receiver itself

introduced by the use of excessive gain form a limiting factor. It has been found that on the ultra-short wavelengths used for television the most serious forms of interference are due to two main causes. First there is the interference due to electro-medical apparatus used for high-frequency diathermy, of which two types are in general adopted. These may be generically described as "spark diathermy" and "valve diathermy."

The former usually consists of a multiple spark-gap

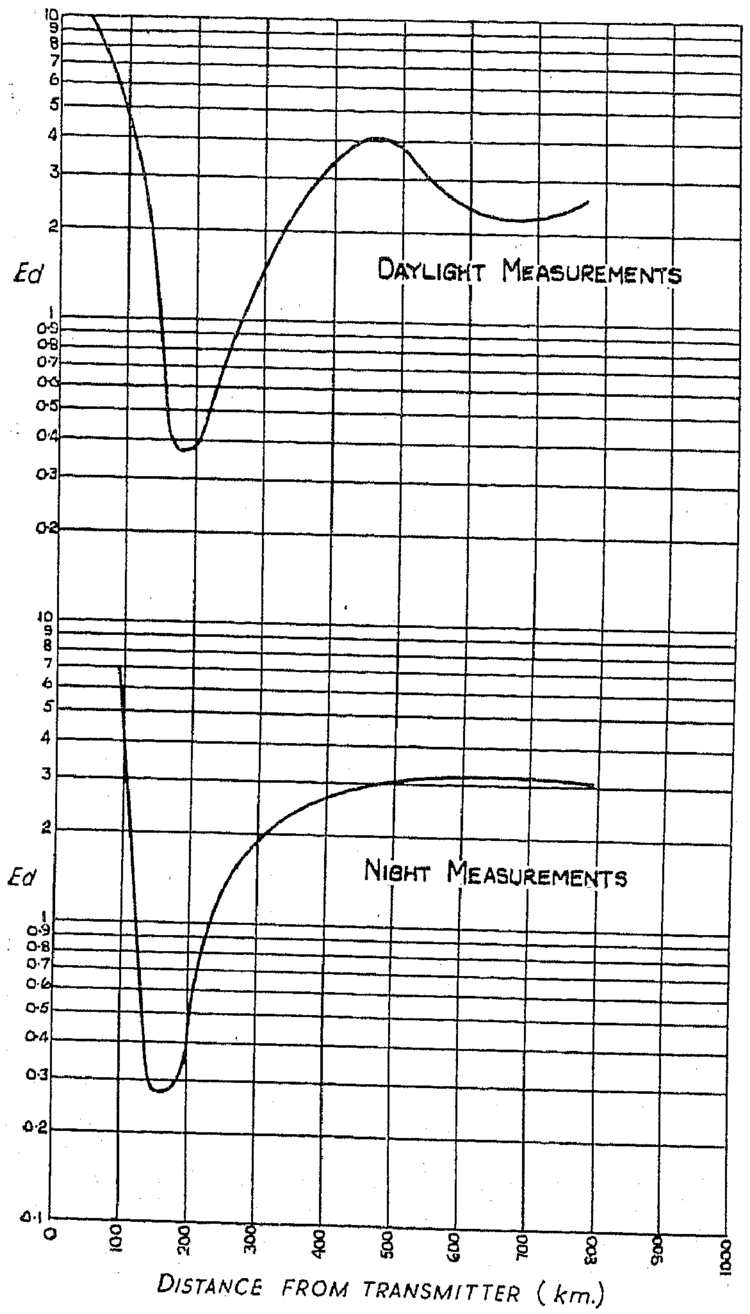

Fig. 19.—Measurements of peak field-strength values.

E = millivolts per metre.
d = distance in km.

supplied with alternating current at high voltage by means of a transformer operated from the supply mains. Associated with the spark-gap is a crude oscillatory circuit having much the same form as that used in early spark transmitting apparatus. Electrodes directly tapped across a part of this circuit are applied to the patient, and currents of the order of some amperes induced into the part under treatment, on wavelengths of from 3 to 10 metres, the actual wavelength being under the control of the operator. Such a machine radiates damped waves having a large band width and possessing great potentialities for interference, which, however, appears to be limited to a comparatively small range, as the radiated wave seems to be rapidly attenuated.

The valve type of machine has in the past consisted of one or more triodes connected to a self-oscillatory circuit, the H.T. supply being provided by self-rectification of the output of a step-up transformer connected to the supply mains. These machines are also capable of being operated from about 5 to 10 metres, and in some cases radiate enormously-strong undamped waves both on the fundamental and on numerous harmonic frequencies. The waves are heavily modulated with supply frequency, together with the many low-frequency harmonics introduced by rectification, and constitute interference of the worst possible type. Frequency-wandering and scintillation are usually present to a very great degree, and it is not uncommon for one of these machines to wander into the television band and obliterate television reception over a comparatively large area, as the undamped waves do not appear to be attenuated rapidly, and their effect is noticeable over surprisingly long distances. Later types of valve apparatus have been provided with high-tension rectifiers and smoothing circuits, which to some extent reduce the interference by confining it to a pure wave.

The suppression of interference from these causes is by no means an easy problem, as it is not sufficient merely to screen the apparatus itself and take adequate precautions to prevent the radio frequency being disseminated through the supply mains, since the greatest source of radiation is the patient himself and the leads connecting the machine to the electrodes applied to him. Further, the use of diathermy apparatus is not, in the case of most hospitals, limited to any one room which could be effectively screened, but rather it is the practice to transport the diathermy apparatus to all wards of the hospital, treating patients in their own beds wherever they may happen to be. The problem is thus materially complicated, as clearly it would be a task of great magnitude—if not impracticable—to screen the whole hospital with that meticulous care which experience has shown to be necessary in order effectively to suppress the interference.

One example of the efficiency of comparatively simple methods of screening a room has occurred in the case of a North London hospital situated about ½ mile from Alexandra Palace, where the use of a spark diathermy machine completely jammed the reception at Alexandra Palace of the 5-metre radio-link transmitter. The whole of the walls and ceiling of the room were covered with aluminium foil, 5 mils in thickness, applied with a paper backing after the fashion of ordinary wallpaper. The joints in the foil were of the butt type, a strip of aluminium foil being laid over the intersection and secured in position by means of a batten, so as to be in intimate contact with the foil on both sides of the joint. At one end of the room, which was open, a partition covered with ½-in. mesh chicken-wire was erected, good electrical connection being maintained between the aluminium foil on the ceiling and walls and the chicken-wire. Chicken-wire screens were placed over the window and laid on the floor underneath the usual rubber floor material. Stopper circuits in the form of radio-frequency chokes with condensers to earth were inserted in all electrical leads

entering the room from outside, the chokes being placed in suitable screening boxes.

This treatment effected complete suppression of the interference, but the necessity for thorough measures was amply demonstrated by the fact that if the screened door in the partition was opened by only a few inches, the interference appeared at a level comparable with that experienced before the work of screening was carried out.

The existence of high-frequency diathermy apparatus is at present largely confined to the West End of London, where many physicians have their consulting rooms, and to a number of hospitals situated both centrally and in the suburbs. As a result of this the interference, while very violent, is not so widespread as the second form of interference previously referred to, viz. that due to the ignition systems of motor-cars.

Practically all types of motor vehicle, particularly those equipped with coil ignition, radiate more or less serious interference in the television band.

The actual carrying power of this interference is not great, being limited in most cases to a few hundred yards, but, nevertheless, the effect can be extremely serious in the case of the receivers where the aerial is situated in close proximity to a main thoroughfare where a large amount of vehicular traffic is constantly passing.

The two worst cases occur in the centre of the City, where, although the television signal is strong, traffic is particularly dense, and in places towards the fringe of the service area of the station where the television signal is weak and the receiver is situated in close proximity to a main road. The only slightly mitigating circumstance arises from the fact that in the outlying districts the volume of traffic is a good deal less, so that the degree of interference decreases at a rate which is somewhat commensurate with the reduction of signal strength. Even so, extremely bad cases occur in the vicinity of main arterial roads, and the only partial remedy which can be found lies in placing the receiving aerial as far as possible from the source of interference, e.g. at the end of a garden remote from the road, leading into the receiver through a suitably screened or balanced high-frequency cable. The use of directional aerial systems in these cases appears indicated, provided of course that the location of the interference sources does not lie in the same direction as the station.

A curious circumstance noticed is that motor-car interference shows a definite peak at about 125 cycles per sec., and, in fact, on listening it is possible to detect a hum of this frequency preponderating over the general indeterminate noise. It has been suggested that this peculiar frequency of the interference arises from the widespread use of 6-cylinder cars driven at a uniform 30 miles per hour in surrounding limited areas.

Assuming that the average circumference of a car wheel is 5 ft. 6 in. and the average back-axle ratio is 5 to 1, the engine speed would be approximately 40 revolutions per sec., which, for a 6-cylinder engine having a 120° crankshaft resulting in three sparks per revolution, should give a prime interference frequency of about 120 cycles per sec. On this basis, a 4-cylinder engine having two sparks per revolution with 180° crankshaft should give about 70 to 80 cycles per sec., and a certain peak of interference at about this frequency is to be noted, although it does not show up so prominently as the 125-cycle component. The above is mentioned merely as a matter of interest, and as being a possible explanation of a pronounced phenomenon for the existence of which no other convincing reason can at present be advanced.

It has been found possible in practice to suppress the effects of motor-car ignition interference by the inclusion of suitable suppressors in the form of resistances in series with the sparking plugs and distributor, or by completely screening the leads associated with the ignition system by means of an earthed metallic braid. A certain divergence of opinion exists as to whether the taking of these steps has any material influence upon the performance of an internal-combustion engine, but the whole matter is being carefully investigated by the Post Office and the Electrical Research Association with a view to drawing up a definite specification for the suppression of interference due to such causes as motor-cars, diathermy, etc.

(d) Types of Receivers and Receiving Aerials

A number of types of receivers have made their appearance on the market in various forms, but in general the cathode-ray tube appears to be used exclusively as the reproduction medium. The receivers divide themselves broadly into two classes, those using a straight radio-frequency amplification of the vision signal and others employing the superheterodyne principle. Of the latter type there is a further subdivision, viz. those receivers amplifying both sidebands of the transmission and those employing single-sideband operation.

In most cases the detector stage, or second detector in superheterodyne receivers, handles signals of fair amplitude and is equipped with two outputs. One output is usually taken to the control electrode of the cathode-ray tube, either direct or through a single vision-frequency amplification stage, which in some cases is a d.c. amplifier and in other cases is an a.c. amplifier having the d.c. component subsequently restored.

The second output from the detector is usually taken to some form of separator stage, which separates the synchronizing impulses from the vision signals and discriminates between line- and frame-synchronizing impulses. The resultant line- and frame-synchronizing impulses are then fed to the respective line- and frame-scanning oscillators, which are thus synchronized with the incoming signal and provide appropriate sawtooth wave-forms to produce the requisite scan.

The cathode-ray tubes vary in size from 9 in. to 15 in. screen diameter, giving picture dimensions varying from 8 in. × 6 in. to 12 in. × 8 in., and either electrostatic or magnetic focusing and scanning or a mixture of both is used. No definite evidence regarding the relative merits of these principles appears at present to exist. Larger cathode-ray tubes having screened diameters up to 24 in. have been made, but have not yet been generally adopted, as their construction presents rather severe problems, related to the effect of atmospheric pressure.

There appears to be a general tendency to standardize on tubes of 12-in. screen diameter, giving a picture approximately 10 in. × 8 in., although certain makers employ larger tubes and others smaller. The problem of

accommodating a cathode-ray tube which may be between 2 ft. and 3 ft. in length in a cabinet of reasonable dimensions has given rise to the exercise of considerable ingenuity in design. The fashion in receivers appears to be fairly equally divided between those in which the cathode-ray tube screen is directly viewed, and those in which it is viewed by means of a mirror forming the top lid of the cabinet. It is generally conceded that the former method of viewing gives greater satisfaction to the viewer, but its use involves severe practical difficulty, necessitating as it does the mounting of the cathode-ray tube in a horizontal position, which in turn implies that the cabinet must be very deep, with the consequence that some difficulty is found in accommodating it in any but large rooms. If, on the other hand, a mirror is used, the cathode-ray tube may be mounted in a vertical position, which results in a cabinet of much more convenient shape. It is of course essential to use front-silvered mirrors to avoid the formation of double images.

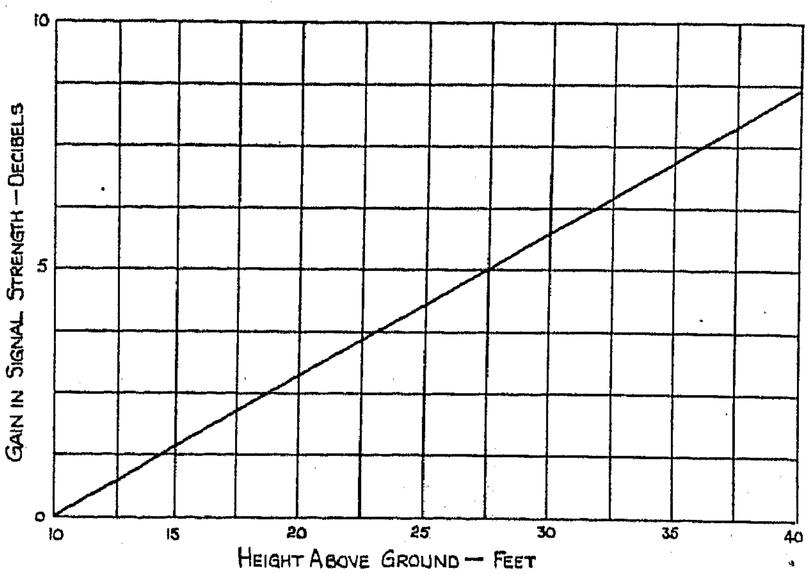

Fig. 20

The advent of television has led to the general use of certain specialized forms of aerials and the development of efficient but inexpensive feeder cables for use with them. The ordinary type of aerial used for sound broadcasting is of but little service for the reception of television, as not only does its response occur at a much higher wavelength, but any attempt to use it as an aperiodic aerial inevitably results in a very poor ratio of signal to interference.

It is the practice, therefore, to mount special types of aerials on the roofs of buildings, often by means of a short mast some 10 ft. or 15 ft. in height, the most general form of aerial to be used being the $\frac{1}{2}$-wave vertical-dipole aerial. This usually consists of a length of copper wire of large diameter, or of small copper tube which is either mounted at its centre so as to be self-supporting or mounted upon the wooden spar by means of stand-off insulators. In the majority of cases the dipole aerial is centre-fed by means of an interruption at its centre point. The two halves of the dipole are frequently connected to a balanced twin feeder having a characteristic impedance of about 120 ohms, so that very fair conditions of matching are obtained. This twin-wire feeder is constructed from two small-diameter copper conductors, embedded very close together in a tube of indiarubber (or gutta percha) and bituminous compound, and has comparatively low losses. It relies upon the proximity of conductors and the fact that it is balanced to ensure that interference due to fields which the cable may traverse cancels out.

An alternative method consists in transforming from a balanced aerial to an unbalanced feeder by means of a $\frac{1}{4}$-wave structure, the feeder in this case taking the form of a coaxial cable, consisting of a central copper conductor and an outside conductor of either lead or copper braid. The space between the conductors is filled up either with paper insulation designed to introduce the maximum of air space or by some low-loss rubber and bituminous compound.

The characteristic impedance of the resultant cable is about 120 ohms, and its losses are relatively low. It relies upon the shielding effect of the outer conductor, which is usually earthed at its lower end, to exclude interference.

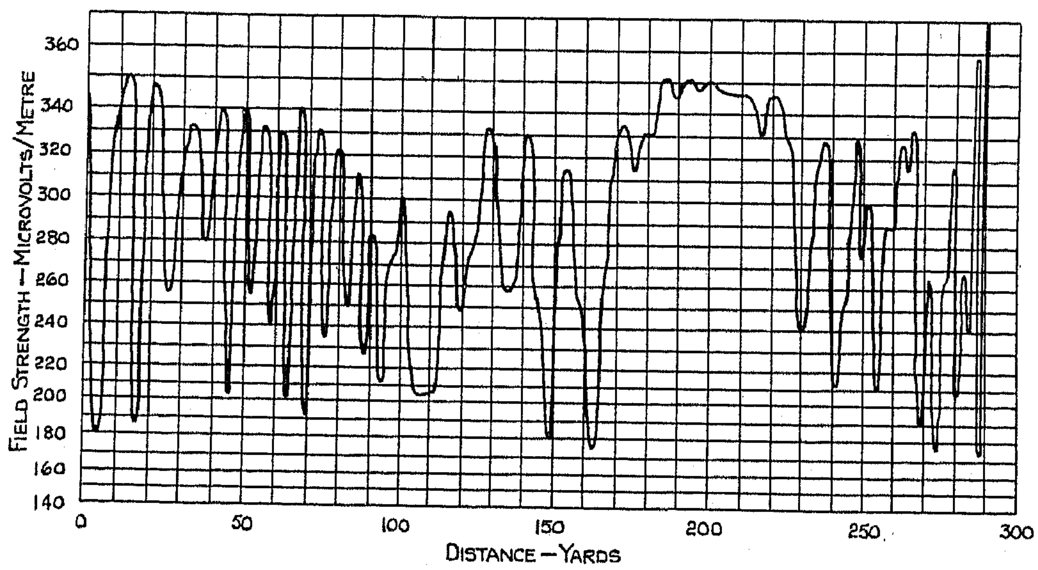

Fig. 21

Some attempts are made to introduce a measure of directivity into the receiving aerial by mounting a second unfed $\frac{1}{2}$-wave dipole at a distance of $\frac{1}{4}$-wave behind the receiving elements. A gain of from 2 to 3 db. in received

signal strength has been recorded for this arrangement. Experiments have been carried out using more complex receiving arrays, including numbers of stack dipoles, inverted V aerials, and various others, but in general these have not as yet been applied to domestic receivers.

As has been previously stated, the effect of height is of great importance. This is illustrated by Fig. 20, showing the gain in field strength plotted against height in a receiving dipole.

Another problem which the receiving aerial brings in its train is the effect of standing waves due to the presence of metal roofs, drainpipes, neighbouring steel-frame buildings, etc. Fig. 21 shows typical effects upon the received field strength which may be encountered by moving the receiving aerial over distances of literally only a few yards. In some cases reflections are received of such delay as to introduce definite multiple images in the received picture, and cases have been recorded where reflections having an extremely long delay have resulted from the existence at some considerable distance of such objects as steel gasometers. Against this, however, it has happily proved to be the experience in general that if some little pains are taken to find a location for the receiving aerial where standing-wave conditions are at their best, and reflections at their minimum, a good result can be obtained in nearly every case.

Sound

Sound reception in practically all television receivers is by means of a separate superheterodyne, operating a loud-speaker suitably placed in the cabinet. In cases where the vision receiver also employs the superheterodyne principle it is not unusual to use a common frequency-changing oscillator for both vision and sound, arranging the intermediate frequency for the sound receiver to be $3\frac{1}{2}$ Mc./sec. lower in frequency than the vision intermediate-frequency.

Receiver Controls

In the case of receivers employing straight radio-frequency amplification of the vision signal, tuning is preset and the only tuning control provided is a trimmer on the frequency-changing oscillator of the sound receiver.

In the case of receivers using the superheterodyne principle for both vision and sound with a common oscillator, an adjustable trimming condenser is usually provided, by means of which the sound signal can be accurately tuned in, arrangements being made before the set leaves the factory that this position corresponds to the optimum tuning point for the vision also.

All types of receivers are provided with a brightness control, which usually varies the standing bias on the control electrode of the cathode-ray tube, and a contrast control which varies either the radio- or the intermediate-frequency amplifier gain or takes the form of a potentiometer across the vision-frequency output after the detector. Some receivers are provided with both of these latter controls, the gain control being used to compensate for variations in signal strength dependent upon the situation of the receiver, and thereafter left untouched. Adjustments to contrast are then made by means of the vision-frequency potentiometer in conjunction with the brightness control, and any desired value of picture contrast may thus be obtained. It is interesting to note that viewers almost invariably seek very "contrasty" pictures at first, but that after a time they tend to reduce the contrast to give a softer effect. The question of colour of the fluorescent screens is of course a matter of taste, and receivers having cathode-ray tubes giving every imaginable shade of green, blue, purple, and sepia, have from time to time made their appearance. While many of these tones are found attractive by some people, the more general taste is for a shade approaching black and white. The majority of receivers now being offered incorporate tubes in which the image is reproduced in a very good range of tones between black and white, with a commendable brightness in the high lights.

ACKNOWLEDGMENTS

The authors are indebted to the Chief Engineer of the British Broadcasting Corporation for permission to publish this paper.

Acknowledgment is also due to Mr. H. L. Kirke, head of the Research Department, and Mr. H. B. Rantzen, head of the Lines Department, and members of their staff, who provided technical information incorporated in this paper; and to Mr. P. A. T. Bevan, of the Station Design and Installation Department, who assisted in its compilation.

Authors' Note.

Certain of the diagrams illustrating this paper have previously appeared in B.B.C. publications, but in the interests of completeness of this paper it is felt that it is not out of place to reproduce them.

[The discussion on this paper will be found on page 793.]

THE MARCONI-E.M.I. TELEVISION SYSTEM

PART I. THE TRANSMITTED WAVE-FORM

By A. D. BLUMLEIN, B.Sc.(Eng.), Associate Member.

PART II. THE VISION INPUT EQUIPMENT

By C. O. BROWNE, B.Sc.

PART III. THE RADIO TRANSMITTER

By N. E. DAVIS and E. GREEN, M.Sc., Associate.

(*Paper read before* THE INSTITUTION 21*st April*, 1938.)

INTRODUCTION

The object of this paper is to describe the radiated wave-form of the Marconi-E.M.I. television system and electrical equipment supplied to the B.B.C. for the London Television Station. Owing to the wide field covered, the paper is written in three Parts, which are in effect three separate closely-related papers.

PART I

THE TRANSMITTED WAVE-FORM

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(*First received* 1*st December*, 1937, *and in final form* 12*th March*, 1938.)

SUMMARY

This Part of the paper describes the technical considerations leading to the choice of the particular wave-form now standardized by the B.B.C. for radiation from the London Television Station. The various characteristics of the system are described, together with the considerations that led to their adoption. A slight modification of the published wave-form specification is suggested. Finally, automatic volume control is briefly discussed. An Appendix gives the modified wave-form specification.

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(1) INTRODUCTION

A system of television, inasmuch as it is chosen for standardization in a particular country or district, is characterized not by the use of a particular type of camera, nor by the use of electrical or mechanical scanning, but by a specification of transmitted wave-form. The fixation of a wave-form may almost certainly imply the use of particular types of apparatus at the transmitter, but such apparatus is largely subservient to the standard chosen. The following paragraphs describe the considerations which led to the choice of the present Marconi-E.M.I. wave-form standard. Headings are given to the sections covering various features of the transmitted wave-form, but a certain amount of overlapping is inevitable owing to the interdependence of the factors involved.

(2) UNIDIRECTIONAL CONSTANT-VELOCITY SCANNING

Although "zigzag" scanning, i.e. scanning where alternate lines are scanned in opposite directions, is attractive for electrical scanning on account of the absence of any very rapid changes of scanning field, its use was not seriously considered in view of the fact that it is unsuitable for mechanical scanners, and also in view of the intolerable accuracy of the scanning wave-form and synchronization required if good pictures are to be reproduced.

Another possible system was one where the scanning velocity depends upon the picture brightness. A complete description of such a velocity-modulated television system is given in Messrs. Bedford and Puckle's very interesting paper.* In this system the velocity of scanning was varied in accordance with the brightness of the area scanned. For high lights the scanning velocity was inversely proportional to the brightness. For dark tones, however, a conventional maximum velocity represented black, brightness control being used at the receiver to supplement the variations in apparent brightness produced automatically by the variable velocity. Apart from convenience or inconvenience of constructing the necessary transmitting and receiving apparatus, velocity modulation from the transmission standpoint is characterized by "implicit" synchronization, in that the scanning-control signals and the brightness-control signals are one and the same. This avoids the necessity for any special synchronizing signals. On the other hand, the position of the scanning spot is an integral of the brightness and conversely the brightness is a differential of the spot position, which leads to serious interference troubles in transmission. These troubles, which are examined in the above-mentioned paper and the discussion following it, were sufficiently fundamental to preclude the use of velocity modulation.

A system was adopted having all the lines scanned in the same direction at uniform speed, which necessitates the transmission of distinct synchronizing and vision signals.

* *Journal I.E.E.*, 1934, vol. 75, p. 63.

(3) MODULATION: A LINEAR FUNCTION OF OBJECT BRIGHTNESS

The vision signals to be transmitted represent from instant to instant the brightness of the picture being scanned, and may have any amplitude between a value representing black and a value representing the brightest part of the picture or "white." The signals may change gradually, as for a gradual shading of the picture, or very rapidly, as for a vertical edge, the ultimate rapidity of change being limited by the size of the transmitting scanning-spot and the frequency-limitations of the transmitting circuits. It should be noted that the vision signals essentially contain all frequencies down to zero and lie one side of the datum level, which is black. The signals in this respect are more akin to telegraph signals than telephone signals. It has been considered whether better transmission could be obtained by distorting the transmitted wave-form from that directly representing brightness, by distorting the frequency characteristic before transmission and correcting at the receiver. A short consideration will show that practically any frequency within the range may be produced at full black-to-white amplitude; so that, if the picture transmitted is not prescribed, any frequency distortion will reduce the transmitted level of some frequencies without enabling the level of any others to be increased. As far as possible, therefore, the vision signals are transmitted with a flat frequency-characteristic.

In current cinematograph technique it is usual to increase the contrast by a factor lying between $1 \cdot 5$ and $2 \cdot 0$, presumably to make up for lack of colour. This factor is usually called γ, the original brightness A of any point being related to the reproduced brightness B by the relation $B = kA^{\gamma}$. Since the eye is approximately logarithmic, this leads to an increase of contrast of approximately γ. This same effect is required in television. The question naturally arises as to whether this should be applied at the transmitter or the receiver. Now a given small change in light intensity at the picture is more noticeable in dark than in light parts of the picture. With a linear characteristic at the receiver, the dark parts of the picture are liable to suffer severely from quite slight interference. By applying the correction at the receiver the sensitivity of the receiver is rendered lower for low light-intensities, so that slight interference is not so noticeable. It is advantageous, therefore, to transmit pictures with unity γ and make any correction at the receiver. This is convenient since any unidirectional control, such as the control of beam current in a cathode-ray receiving tube, is likely to be curvilinear in the required sense. Theoretically, assuming a logarithmic sensation law for the eye, a logarithmic transmitting distortion with exponential receiving characteristic is indicated, but such an arrangement is hardly considered practicable, if really desirable; and so far, despite its advantages, has seldom if ever been applied even to sound transmission.

The above arguments lead to the transmission of a signal, as far as possible undistorted in frequency or amplitude, representative of the brightness of successive elements of the picture scanned with a constant scanning velocity.

(4) DOUBLE-SIDEBAND AMPLITUDE MODULATION

The next consideration is the modulation of a radio signal for broadcasting. It was considered that phase modulation of a wave containing frequencies down to and including zero would give a wave which could not be demodulated at the receiver without resorting to some special device such as another radiated carrier at multiple frequency which could be used as a reference carrier. Single-sideband working at the transmitter was similarly considered, in the hope of reducing the space occupied in the ether. No advantage would be obtained by such an arrangement unless one sideband was suppressed substantially completely, at least for all but the lowest modulation frequencies. In view of the necessary wide band-width extending down to zero frequency, and the strict phase requirements for television transmission, no practicable method of single-sideband transmission was discovered. The mere tapering-off of signal strength for one of the sidebands has no particular advantages for the transmitter. A straightforward double-sideband amplitude modulation was therefore adopted.

(5) "INFRA-BLACK" PULSE SYNCHRONIZING

Before considering the direction and range of modulation, it is necessary to consider how the synchronizing signals are to be transmitted. For convenience of reception it is very advantageous to transmit the synchronizing signals on the same carrier as the vision signals. Furthermore, although in the case of a perfectly uniformly-running scanning system there is no continuous transmission of intelligence by synchronizing signals, nevertheless it is highly advantageous under practical working conditions to provide the receiver with an accurate synchronizing signal between each line and the next, so that a satisfactory picture may be obtained with scanning circuits composed of comparatively unstable commercial components. In fact, it is desirable that the synchronizing signals should be such as to permit of a receiver being worked asynchronously, much after the manner of a "start stop" telegraph printer. This requirement calls for line signals of a sharpness comparable with the vision signals, i.e. containing a wide band of frequencies. A further increase of the required band-width due to supplying a sub-carrier or separate carrier for the synchronizing signals appears highly undesirable, and the synchronizing signals are therefore transmitted on the same carrier as the vision signals, being differentiated therefrom by difference of amplitude of modulation.

As explained above, the vision signals lie within a range limited by black and white (representing the brightest part of the picture). Synchronizing signals can therefore be transmitted as signals lying beyond the black or white, outside the vision-signal range. Such signals may be spoken of as "blacker than black" or "infra-black" if outside the vision-signal range in the black direction, or "whiter than white" or "ultra-white" if outside in the white direction. If ultra-white synchronizing signals are employed it is necessary to provide special and rather complicated means at the receiver to prevent these synchronizing pulses from appearing on the picture. If synchronizing signals are employed in the infra-black

these signals will not, with the majority of receiver types, appear on the receiver screen, since the majority of light-control devices are unaffected by a signal greater than that necessary to obscure the light. This great advantage of requiring no special synchronizing signal-obscuring device at the receiver has led to the adoption of infra-black synchronizing signals. In this connection it should be noted that there is a possible workable system employing ultra-white synchronizing pulses extending down to zero radiated carrier, with black representing peak carrier. This system has the merit of providing simple A.V.C. (automatic volume control) and noise suppression at the receiver, but on the other hand a comparatively complex arrangement is necessary for preventing the ultra-white signals from appearing on the screen. The infra-black system adopted can supply A.V.C. and noise suppression with no more, or even less, complex equipment than is required for pulse suppression by the above ultra-white system. Further, for a simple receiver the infra-black receiver is less complex than the ultra-white.

(6) D.C. TRANSMISSION*

Before discussing the exact form of synchronizing pulses it is necessary to consider what is known as d.c. working. Owing to the difficulties of making satisfactory high-gain d.c.-coupled amplifiers, most television amplifiers have in the past been a.c.-coupled, so that the resultant vision wave has been an a.c. wave, lying about a mean value, rather than a d.c. signal referred to a datum level of black. Now with an a.c. television signal the amplitude of black relative to the mean line is a variable amount depending on the nature of the picture. With a white dot on a black background the black will be close to the mean line. For a black dot on a white background, the black will lie remote from the mean line. A change in the nature of the picture will cause a wander of the amplitude of the black signal. Now at the receiver it is necessary to separate the vision signals from the synchronizing signals so that the latter may be used to control the scanning. An " infra-black " synchronizing signal can be separated by a " separator " device set to pass signals beyond a certain amplitude in the black direction. If, however, the black level is liable to wander at the separator, it is necessary to employ large synchronizing signals so that no possible amount of " wander " will cause either vision signals to be passed by the separator or synchronizing signals to be missed by the separator. The size of the synchronizing signal required at the receiver may be greatly reduced by ensuring that the signal at the separator is a d.c. signal, i.e. a signal having a definite amplitude for black irrespective of the nature of the picture. The d.c. signal may be obtained either by transmitting the d.c. signal or by converting the a.c. signal to a d.c. signal by " d.c. re-establishment " at the receiver. This latter process relies on the synchronizing signals being of fixed amplitude and comparatively free from interference. The same " wander " which makes separation difficult with an a.c. signal, causes an a.c. signal to be unsatisfactory from the transmission standpoint. As the black-to-white amplitude is fixed, the liability of the absolute value of black to wander means that the whole signal may occupy a range of absolute values greatly in excess of the difference between black and white. It is therefore necessary to provide larger equipment to accommodate the extra amplitude-range produced by the " wander." Furthermore, any slight amplitude-characteristic curvatures will variably affect the signals as the " wander " takes place. The transmission of an a.c. modulation therefore involves for a given available transmitter-power much smaller useful signals at the receiver; and, although the difficulty of synchronization-signal separation can be got over by d.c. re-establishment at the receiver, this may not be very satisfactory in the presence of interference, especially as with a.c. transmission the synchronizing signals cannot, owing to the wander, be kept in a part of the modulation characteristic comparatively free of strong interference [see tests described in Section (6)]. The transmission of a d.c. modulation has therefore been chosen, i.e. definite carrier values represent black, white, and the synchronizing signal. There is no fixed mean carrier value, as this depends on the picture brightness. The system of transmission is analogous to telegraphy rather than telephony.

For lack of a better word, " carrier " is here used as representing the instantaneous radio-frequency output of the transmitter in amperes or volts in the aerial, the reference value being the peak output of the transmitter. This use differs from that employed for telephony transmission, where the word " carrier " refers to what would be called " mean carrier " or " average carrier " in this paper.

* P. W. Willans: British Patent No. 422906 (E.M.I.)

(7) POSITIVE MODULATION AND 30 % SYNCHRONIZING PULSE

" Infra-black " synchronizing and d.c. transmission having been decided upon, it remains to fix the direction and limits of modulation. If the synchronizing signals are represented by a high carrier (" negative modulation ") they will be very prone to interference, which increases the amplitude and so, in effect, produces at the receiver super-strong synchronizing pulses. Such strong pulses may greatly disturb the picture-scanning. On the other hand, white being represented by a low carrier value, larger ultra-white signals than those represented by zero carrier cannot be produced, and this reduces the brightness of severe interference. If, however, " positive modulation " is employed, in which synchronizing signals are represented by a low (and, very preferably, practically zero) carrier while white is represented by a high carrier, super-strong interfering synchronizing pulses cannot be experienced. This enables comparatively small synchronizing signals to be employed while satisfactory synchronization is still given. With this arrangement strong ultra-white signals can be produced by interference, but these signals are less irritating than the breaking-up of the picture produced by the interference giving super-strong synchronizing pulses. Of course, with negative modulation a carefully designed limiter could be used at the receiver to ensure that the scanning generators could only be affected by signals of the exactly correct amplitude. It is thought that such a limiter would be very difficult to adjust for all reception conditions, and if made self-adjusting would be upset by very severe interference. A

similar limiter, not requiring as sensitive an adjustment, may be used for suppressing interference when positive modulation is employed.

Tests were carried out some years ago from Hayes, Middlesex, to St. John's Wood in order to compare positive- and negative-modulation reception in the presence of interference. The initial tests were made using synchronizing signals equal in amplitude to the vision signals. With negative modulation the interference gave rise to breaking-up of the whole picture. A considerable improvement was obtained by changing to positive modulation, the white flashes produced by interference being much less irritating than the breaking-up of the picture. Better results still were obtained by modulating so that the synchronizing signal was represented by practically zero carrier. With this condition satisfactory synchronizing under interference conditions could be obtained with synchronizing signals of only one-fifth the vision amplitude. No interference can possibly produce a field strength, and hence detector output, less than zero, so that by modulating down to zero carrier for synchronizing signals no super-strong interfering synchronizing pulses can be produced, and hence very good interference-free synchronizing is obtained at the receiver. These tests led to a definite decision to adopt a system with substantially zero carrier representing the synchronizing signal and with peak carrier representing white. The diminishing return of increased vision signals produced by reducing the synchronizing signal down to one-fifth the vision signal led to the adoption of a synchronizing signal of three-sevenths of the vision signal.

(8) CONSTANT-AMPLITUDE RECTANGULAR SYNCHRONIZING PULSES

A further advantage of working down to zero carrier with the synchronizing pulses is that these pulses occupy the necessarily curved bottom bend of the transmitter modulation characteristic, so that efficient use is made of a part of the characteristic unsuitable for vision signals. It is of course necessary that a d.c. modulation be employed, both to prevent the synchronizing signals from wandering away from zero carrier and to prevent them being crushed out altogether round the bend of the characteristic. Provided all synchronizing signals are made rectangular in wave-shape and of equal amplitude, the operation on a curved characteristic does not affect their shape but only their size, which can be allowed for by increasing the input of synchronizing signal to the modulator. Furthermore, it is practically necessary for the line-synchronizing signals to have a square (within the limits of the frequency range) leading edge in order to achieve accurate synchronizing as explained above. All synchronizing signals have therefore been made rectangular and of equal amplitude so that they can suffer amplitude distortion without distortion of shape. This feature is most important, as it allows the synchronizing signals to be crushed considerably without losing timing accuracy. Furthermore, they may be restored, if desired, to their original amplitude after crushing; this feature is of some importance when radio relays are being operated.

(9) 50-FRAMES-PER-SECOND INTERLACED SCANNING

At the beginning of 1934, when the originators of the system here described were working with 180 lines and sequential scanning at 25 frames per sec., the cathode-ray receiving tubes used were not at all bright. With a poorly illuminated picture at the receiver the 25-cycle flicker was not very objectionable, but as receiving tubes became brighter it was obvious that 25-cycle flicker would be unacceptable in practice. The present system of interlacing was therefore adopted.* In such a system the picture is completely scanned in $\frac{1}{25}$ sec. by means of two downward traversals or frames, each of $\frac{1}{50}$ sec. duration. The lines constituting one such frame are arranged to lie between the lines of the other frame so as to give good picture detail. The process is analogous to the device used in film projection, whereby it is arranged that although only 24 pictures are shown per second, each picture is thrown on the screen 2 or 3 times so as to raise the light-flicker frequency to 48 or 72 flashes per sec. Similarly, with interlaced scanning the spot traverses the frame 50 times per sec., thus raising the flicker above that perceptible to the human eye. The feature of this particular interlacing system is that both the line-traversals and the frame-traversals are entirely regular, the interlacing being effected by fixing an odd number of lines to a complete picture, i.e. an integer plus a half number of lines to each frame. With regular scanning traversals, an interlaced picture results. This process is explained in greater detail in the Appendix.

A frame frequency of the order of 50 was necessary in order to overcome flicker, and the exact value 50 was chosen on account of the supply frequency in this country. Receivers built to operate from the 50-cycle mains, always have some slight residual hum which either darkens or brightens parts of the picture, or produces a slight distortion of the frame. If the frame frequency is synchronous, or very nearly synchronous, with the supply frequency, these effects are stationary, or move very slowly across the picture, in which case they are not nearly so noticeable to the eye as when moving rapidly across the picture. Experiments on a cathode-ray-tube receiver worked from 50-cycle mains showed that residual-hum effects which could not be detected when scanning took place at 50 frames per sec. were quite intolerable at 37·5 frames per sec. Furthermore, the smoothing and magnetic shielding required for operating at 37·5 frames per sec. were such as to increase the cost and size of receivers very seriously. It was therefore decided to adopt 50 frames per sec. and where possible to hold this frequency in synchronism with the grid supply.

(10) 405-LINE SCANNING

After the 180-line scanning mentioned above had been abandoned, a system was adopted using a 243†-line picture at 50 frames per sec. (interlaced) to give 25 complete pictures per sec. It was decided, however, to recommend to the Television Commission a specification based on 405 lines, so as to provide a system which might remain stable for a reasonable length of time. This

* R. C. Ballard: British Patent No. 420391 (R.C.A.).

† The number 243, and also the later number 405, were chosen as being multiples of small odd integers, which facilitated the electrical interlocking of the line and frame frequencies required for interlacing.

recommendation was not given without considerable misgivings, since it involved an increase of 67 % in the line-scanning speed and an increase of 2·8 times in the frequency band-width over those employed for the 243-line system which had recently been developed. These misgivings were in no way allayed by the thought that the system must work in competition with a developed 240-line system, which might in the initial stages give more detail on early receivers of poor band-width. During the period before the station operated, however, transmitting apparatus was considerably improved and the receiver manufacturers designed good receivers, so that tolerably good 405-line pictures were obtained. It is a considered opinion that the present transmitted and received pictures can be considerably improved in detail without exhausting the possibilities of the present system.

(11) INTERVALS BETWEEN LINES AND FRAMES

The values 50 frames per sec. and 405 lines having been chosen, it was necessary to determine arbitrarily the time-intervals between successive lines and frames to which the receiver must be designed to work. These time-intervals are needed at a cathode-ray receiver for the return stroke, by which the cathode-ray beam is returned from the end of one line or frame to the beginning of the next. Actually the beam is turned off, or " blacked out " during the return stroke, nevertheless the electric or magnetic field controlling beam-deflection must be altered just as though the beam were there to perform the return stroke. Obviously such electric or magnetic fields cannot be altered instantaneously at the end of each line or frame, and thus time-intervals are necessary if some of the picture is not to be missed. With mechanical receivers using rotating scanning means, successive lines are scanned by different mechanical elements, so that one line may be scanned from the instant the previous line-scan terminates. With such an arrangement, absolutely perfect phase synchronization would be necessary to prevent the beginning of a picture being cut off and folded round to the end of the picture. Intervals between lines and frames therefore provide a small black edge round the picture which allows for a small phase-error in the mechanical scanning.

Owing to various difficulties with the original 243-line scanning equipment, the transmitted picture originally had intervals between successive lines of about 35 % of the line period, and between successive frames of about 20 % of the frame period. This meant that only 65 % of the line and 80 % of the frame was employed, giving a time (or frequency band-width) efficiency of only 52 %. It was obvious at the time that this efficiency would ultimately be considerably improved, and it was therefore decided to fix the minimum transmitted intervals between lines to which receivers must be designed, and to improve the transmitter as much as possible as time went by—until the minimum intervals were effective for the transmitted picture. The transmission of pictures with longer intervals between lines than are required by the receiver produces only a black border round the picture and consequently a diminution of received picture size or detail. On the other hand, the transmission of intervals shorter than the receiver is designed to take will cause a folding-over of the picture and consequently poor or useless results. The minimum intervals were therefore fixed with reference to receivers only, so that even if the transmitter failed to realize these short intervals initially it could be improved later to enable it to give full efficiency. At the same time these minimum intervals were inserted in the wave-form specification so that receivers could be designed with reference to possible future transmissions.

Considering cathode-ray receivers, the total line period for a 405-line system is approximately 100 microsec. (more exactly, 98·8 microsec.), whereas a frame period is 20 000 microsec. It is therefore obvious that it is possible to reverse the scanning field (electrostatic or electromagnetic) in a shorter fraction of the frame period than the line period. The intervals between frames may therefore be a smaller fraction of the frame period than the intervals between lines are of the line period. On the other hand, the intervals between frames should be longer than the intervals between lines, and this for two reasons. First, the frame frequency is much lower than the line frequency, so that the electrical components of the frame-scanning circuit (transformers, and coupling condensers) have longer time-constants and are usually physically bigger, and thus the unwanted strays are greater than for the line-scanning circuit. This makes it more difficult to reverse the frame-scanning field quickly (say, in less than the duration of one line). Secondly, since all synchronizing pulses are rectangular and of equal amplitude the frame signals are differentiated from the line signals only by the long duration of the former. If the frame-scanning signals only are to trip the frame-scanning mechanism, some time must elapse between the end of the picture signals of one frame (which is the earliest moment that the frame-synchronizing signals can conveniently be transmitted) and the beginning of the frame return stroke, in order that the long frame-synchronizing signal may be transmitted and operate the receiver. The interval between frames was therefore fixed arbitrarily at about one-third the fraction of the frame that the interval between lines was of the line.

It appeared also that the intervals between lines must be fixed arbitrarily, there being no means of calculating a " correct " value. On the one hand the natural desire to save time and the belief that scanning-circuit technique would improve, called for a short interval. On the other hand, the necessity of keeping receiver costs down, and the probable future use of very high voltages and big beams with consequent large stored scanning-field energies, called for a long interval. After much consideration the minimum interval between the picture signals of successive lines was fixed at 15 % of the total line period (14·8 microsec.), and the minimum interval between the vision signals of successive frames was fixed at 10 lines (4·94 % of the total frame period). This gives a time efficiency of 80·8 %. Any attempt to raise this figure to 90 % would lead to very severe difficulties in connection with scanning cathode-ray receivers. As regards mechanical receiveıs, it appears also reasonable to give a bigger percentage interval between lines, since the scanning speed is high for lines and the phase accuracy probably more difficult to obtain.

(12) WAVE-FORM SPECIFIED

The main technical considerations affecting the system having been fixed, it remains to fix conventions of scanning directions, the picture height/width ratio, and the duration of synchronizing impulses. The Appendix gives a specification of the radiated wave-form, together with an explanatory drawing. This specification is similar to that published at the beginning of October, 1935, except for the two slight modifications which are described below.

The direction of line and frame scanning was arbitrarily chosen as left to right and top to bottom, in deference to the normal writing directions. The ratio of picture width to picture height was chosen as 5 : 4, as a compromise between 1 : 1 to give maximum area in a circular cathode-ray tube and the 3 : 2 ratio popular in photography. The line-synchronizing signals occupy the first 10 % of the 15 % intervals between lines, leaving a minimum 5 % " black " interval between the end of a line-synchronizing pulse and the beginning of the picture signals. It might be argued that, there being 15 % available, the whole period should have been used for the synchronizing pulse. Actually, except under conditions of very severe and rather freak interference, a line-synchronizing pulse of 1 % or 2 % would be adequate, since only the leading edge of the line pulse is used in practice to trip the line-scanning mechanism. The use of all of a 10 % pulse would only leave 5 % for the whole mechanism of the return stroke. Further, the 5 % black is extremely useful. Without it the only indication of the level of black would be the intervals between synchronizing pulses between frames, which only occur every $\frac{1}{50}$ sec., and represent a very small fraction of the total time of a frame. The 5 % black between lines gives a continuous indication of black level, line by line, which is of great value both for adjusting the transmitted wave by observation of an oscillograph, and for controlling it electrically. For example, the receiver used to receive a radio signal from the mobile transmitter for outside broadcasts has a high-speed A.V.C. to deal with possible reflections from moving objects in the vicinity of the transmitting aerial. This control is worked by observing electrically the received amplitude-difference between synchronizing impulses and this 5 % black.

It is very desirable in cathode-ray-tube receivers to keep the line-scanning mechanism running smoothly during the interval between frames. With this object in view the frame-synchronizing signal is broken up into pulses so that the leading edge of a pulse replaces the leading edge of a line-synchronizing pulse.* Leading edges of synchronizing pulses therefore occur regularly at line frequency throughout the transmission. Since half the frame-synchronizing signals occur half a line out of step (relative to the lines) with the other half, the frame signals are broken up at double line-frequency, so that the total frame signal is identical in each frame. The total frame-synchronizing signal is therefore composed of a number of signals 40 % of a line long separated by 10 % of a line, two such pulses and two intervals occupying a total line. The 10 % interval allows a suitable differentiating circuit in the line-scanning control to accept the leading edge of the frame-synchronizing signal in place of the leading edge of the line signal. As originally specified there was any number of frame pulses between 6 and 12, no definite number being stated, since it did not appear to be of interest to the receiver manufacturer and it was then thought that the exact number would be rather difficult to control at the transmitter. The B.B.C. have fixed the number of pulses at 8. These occupy 4 out of the minimum 10 lines' interval, and for the remaining 6 lines normal line-synchronizing signals with black picture signals between are transmitted. Again, it might be argued that the whole interval between frames should be filled with frame signals. Eight frame signals represent 32 times the integrated synchronizing-signal strength of a line signal, which should be sufficient for differentiating between the two types of signal. Further, the 6 lines of black give the line-scanning mechanism a chance, before the picture begins, to recover from any slight upset due to being operated from long frame-synchronizing pulses instead of short line pulses. The specification given in the Appendix has been modified to fix the number of frame pulses at 8.

* W. S. Percival, C. O. Browne, and E. L. C. White: British Patent No. 425220 (E.M.I.).

(13) WAVE-FORM ACTUALLY RADIATED

Transmissions using the wave-form specified above have been radiated from Alexandra Palace for over a year, and the wave-form adopted has, it is thought, proved reasonably satisfactory. The intervals between transmitted line vision signals have been reduced to practically the specified minimum, except for a small additional interval before the synchronizing pulse (which will be dealt with below). The interval between frames has not been reduced to the minimum 10 lines, owing to the method of film scanning at present employed. An interval of 20 lines is employed, 5 of the additional " black " lines being put in before the synchronizing pulse and the remaining 5 being added on to the end of the specified 10-line minimum interval. That is to say, between frames there occur 5 black lines before the beginning of the frame-synchronizing signal, and 15 black lines after the beginning of the frame-synchronizing signal, these 15 lines including, of course, the 4 lines occupied by the frame-synchronizing pulses. It would be possible to send direct vision pictures (anything other than cinema film) with the minimum 10 lines' interval, but such a procedure would mean rather extensive re-adjustment of the apparatus prior to transmitting film. Such a procedure is unworkable at Alexandra Palace, where film transmissions are interspersed with studio pictures, the two often being worked in conjunction. It is hoped in the future, however, that the method of film transmission will be altered so as to allow the minimum 10-line interval to be realized from the transmitter. Such a change appears trivial, but it does represent a 5 % improvement in effective picture detail, and is considered to be well worth while.

The original specification of radiated wave-form was incomplete in one respect. As specified under minimum-interval conditions, and as shown on the drawing, the beginning of line-synchronizing signals was coincident with the end of the vision signals of the line. Such coincidence with instantaneous change from white to synchronizing is impossible with finite frequency band-

widths. Even were such a signal radiated, it would lead to trouble in a receiver of finite band-width, inasmuch as the line synchronizing would be affected by the vision signals immediately preceding the line-synchronizing signal. The effect of this would be a slight distortion of vertical edges in dependence on the signal brightness on the right-hand edge of the picture. The specification should have contained a reference to a minimum additional interval prior to the line-synchronizing signal of 0·5 % of a line, making the total minimum interval between the vision signals 15·5 %, of which 0·5 % precedes and 15 % follows the beginning of the line-synchronizing signal. This additional minimum interval has in fact always been present in all transmissions radiated from Alexandra Palace on the Marconi-E.M.I. system, the apparatus being set to give an interval of between 0·5 % and 1 % between cessation of vision signals and beginning of line synchronizing. The existence of some interval between vision and synchronizing signals is a practical necessity at the transmitter, so as to give a tolerance which ensures that the vision and synchronizing signals do not get mixed. On the other hand, a reference to the minimum value of the interval should have been made in the specification, since such a minimum value is of slight interest to the receiver manufacturer, as indicating the frequency band-width necessary in order to obtain perfect separation of synchronizing signals. The specification given in the Appendix has been amended to correct this defect.

(14) AUTOMATIC VOLUME CONTROL

Before closing this discussion of the system specification it is well to consider whether the wave-form provides for facilities which may be required in the future. It has often been pointed out that an a.c. transmission system provides automatic volume control (A.V.C.) for television in the same manner as it is available for sound reception. With an a.c. system, however, the A.V.C. must certainly operate very slowly so as to be unaffected by frame frequency, and therefore it will not be suitable for correcting variations of signal-strengths due to objects moving rapidly near an aerial. Further, the simplification of A.V.C. claimed will hardly justify the increased receiver size necessary to avoid overloads from "wandering" signals, and the reduced signal-strength due to poor use of the transmitter.

Again, it has been pointed out that a d.c. transmission with negative modulation provides simple A.V.C. by observation of the peak synchronizing amplitudes. This is admittedly the case, but any simplicity of A.V.C. is, it is thought, outweighed by the complexity of the limiter necessary to suppress false synchronization.

With the system here described, A.V.C. has not in general been found necessary on the wavelengths at present used. Were an A.V.C. required, however, the necessary control might be obtained by observing the black-level amplitude which always follows a synchronizing signal. The necessary pulse for controlling such a device can, for example, be obtained by differentiating the synchronizing pulse and using the trailing edge. There are a number of circuit arrangements available, and the extra equipment involved constitutes a small addition to the multi-valve television set. Furthermore, with synchronizing signals extending to zero, the arrangement can be made such that it cannot "lock" in a position of maximum receiver sensitivity, provided this maximum sensitivity is not so great as to overload the receiver completely with surface noise. If desired, a limiter may then be added to suppress interference flashes on the screen, the setting of the limiter being much less critical than in the case of the limiter which is practically a necessity for a negative-modulation system.

(15) ACKNOWLEDGMENTS

The fixation of the system described in this paper is the result of many years of experimental work and discussion in the Research Laboratories of Electric and Musical Industries, Ltd., in which many engineers were involved. Acknowledgments are due to Mr. I. Shoenberg, the Director of Research; to Mr. G. E. Condliffe; and to the staff of the Research Department. Among the many members of the staff who made valuable contributions to this work are Mr. C. O. Browne and Mr. P. W. Willans.

APPENDIX

Amended Specification of Radiated Wave-form

The Marconi-E.M.I. television system transmits 25 complete pictures per sec., each of 405 total lines. These lines are interlaced so that the frame and flicker frequency is 50 per sec. The transmitter will radiate signals with sidebands extending to about 2·5 Mc./sec.* on either side of the carrier frequency. The transmitted wave-form is shown in Fig. 1.

(a) Line frequency.

10 125 lines per sec., scanned from left to right when looking at the received picture.

(b) Frame frequency.

50 frames per sec., scanned from top to bottom of the received picture.

(c) Type of scanning.

The scanning is interlaced. Two frames, each of 202·5 lines, are interlaced to give a total of 405 lines with a complete picture speed of 25 per sec. The line component and the frame component of scanning are regularly recurrent, the interlace being derived from the fractional relationship between line and frame frequencies. An explanation of the method of interlacing is given at the end of this specification.

(d) Interval between lines.

There will be intervals between the vision signals of successive lines; these intervals provide time for the transmission of a line-synchronizing signal and also for the return of the cathode-ray beam to the beginning of the next line. The minimum interval between the vision signals of successive lines will be 15·5 % of the total line period (1/10 125 sec.); the first 0·5 % of this interval corresponding in intensity to black and constituting a short black interval separating vision signals from the beginning of the line-synchronizing signal; the next 10 %

* The original specification gave the modulation band as 2·0 Mc.

being occupied by the line-synchronizing signal; and the remaining 5 % again corresponding in intensity to black and separating the end of the line-synchronizing signal from successive vision signals.

(e) Interval between frames.

There will be intervals between the vision signals of successive frames. The minimum interval between frames will be 10 lines, leaving a maximum of 192·5 active lines per frame, or 385 active lines per complete picture.

(h) Vision modulation.

The vision modulation is applied in such a direction that an increase in carrier represents an increase in picture brightness. Vision signals occupy values between 30 % and 100 % of peak carrier. The amount by which the transmitted carrier exceeds 30 % represents the brightness of the point being scanned.

(j) Synchronizing modulation.

Signals below 30 % of peak carrier represent synchronizing signals. All synchronizing signals are rectangular

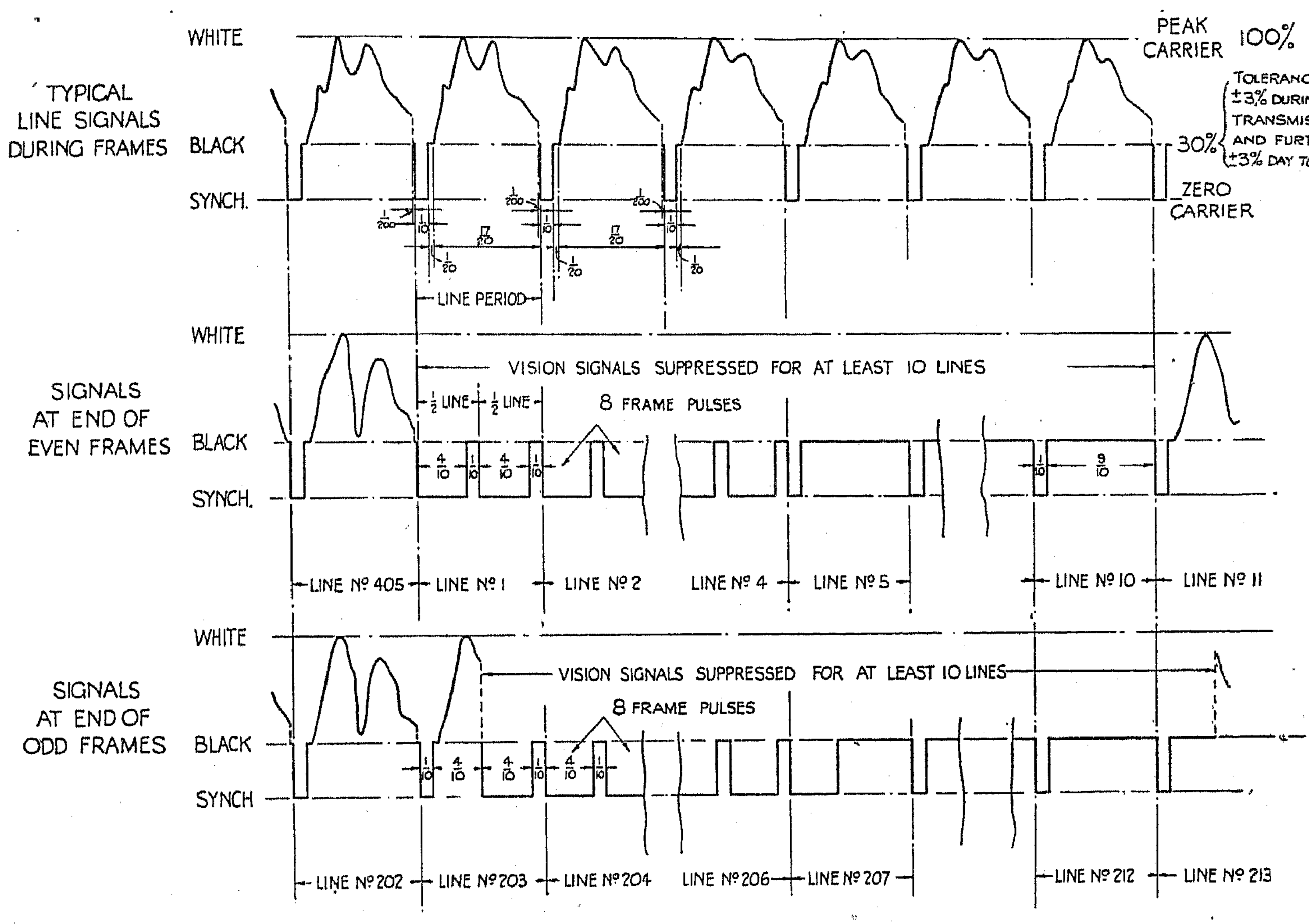

Fig. 1.—Marconi-E.M.I. television system: transmitted wave-form.

(f) Picture ratio.

The picture ratio will be 5 : 4, i.e. the distance scanned during the active 84·5 % of the total line period will be 5/4 times the distance scanned during the 192·5 active lines of the frame.

(g) D.C. modulation.

The picture-brightness component (or the d.c. modulation component) is transmitted as an amplitude modulation, so that a definite carrier value is associated with a definite brightness. This has been called "d.c. working," and results in there being no fixed value of average carrier, since the average carrier varies with picture brightness. The radio-frequency transmitter output is specified in what follows as a percentage of the peak output. This percentage is in terms of current (or voltage) and not in terms of power.

in shape and extend downwards from 30 % peak carrier to effective zero carrier.

(k) Line-synchronizing signals.

The line-synchronizing signals are of one-tenth of a line duration, and are followed by a minimum of one-twentieth of a line of black (30 % peak) signal.

(m) Frame-synchronizing signals.

The frame-synchronizing signals comprise a train of two pulses per line, each occupying four-tenths of a line and having one-tenth of a line interval of black (30 % peak) signal between them. At the end of even numbers of frames the first frame pulse starts, coincident with what would have been a line signal; and at the end of odd numbers of frames the first frame pulse starts half a line after the preceding line signal. Each frame signal con-

sists of 8 pulses, occupying 4 lines. During the rest of the intervals between frames, normal line-synchronizing signals will be transmitted, with black (30 % peak) signals during the remaining nine-tenths of the line.

It will be noted that throughout the interval between frames (as during the whole transmission) the carrier falls from 30 % to zero regularly at line frequency and in phase with the beginning of the normal line-synchronizing pulses.

(n) Variations in transmitted wave-form.

The 15·5 % interval between vision signals of successive lines, and the 10 lines' interval between successive frames, are minimum intervals used at the transmitter. During the initial development of the transmitter certain transmissions may have longer intervals between lines and between frames, corresponding to the transmission of a black border round the picture.

The 30 % carrier is the "black level" below which no vision signals exist and above which no synchronizing signals extend. The mean black level of any transmission will be (30 % ± 3 %) of peak carrier. The black level during any one transmission will not vary by more than 3 % of peak carrier from the mean value of that transmission.

The residual carrier during the transmission of a synchronizing pulse will be less than 5 % of the peak carrier.

The line frequency and the frame frequency will be locked to the 50-cycle supply mains, and therefore will be subject to the frequency variations of the mains.

Explanation of Method of Interlacing

The method of interlacing is demonstrated in Fig. 2, which represents the top and bottom portions on the scanned area with the distance between the lines very much enlarged. The lines show the track of the scanning spot, which moves under the influence of a regular downward motion (frame scan) with quick return and a regular left-to-right motion (line scan) with very quick return (not shown in Fig. 2). The combination of these motions produces the slightly-sloping scanning lines. Starting at A, not necessarily at the beginning of a line, the spot completes the line AB, returns to the left and traverses line CD, then EF, and so on down the "dotted" lines on the drawing. At the bottom of the frame the spot travels along line GH and then starts at J and travels to K. At this point the return stroke of the frame motion begins, and returns the spot to L at the top of the frame. A complete frame-scan has now been made since leaving A, so that 202½ lines have been completed, and the point L is half a line away from A. The downward frame motion now starts again, causing the spot to travel along LM, completing a single line motion JKLM. The spot then returns to the left and traces out line NO, which, owing to L being half a line ahead of A, will lie between lines AB and CD. Similarly the next line (PQ) will lie halfway between CD and EF. The spot now traces down the chain-dotted lines to RS and finally traces out TU. At U the frame-return causes the spot to rise again to the top. When the spot reaches the top it will have completed 2 frames since leaving A, and as two frames occupy the time of exactly 405 complete lines the spot will return exactly to A, after which the cycle begins again.

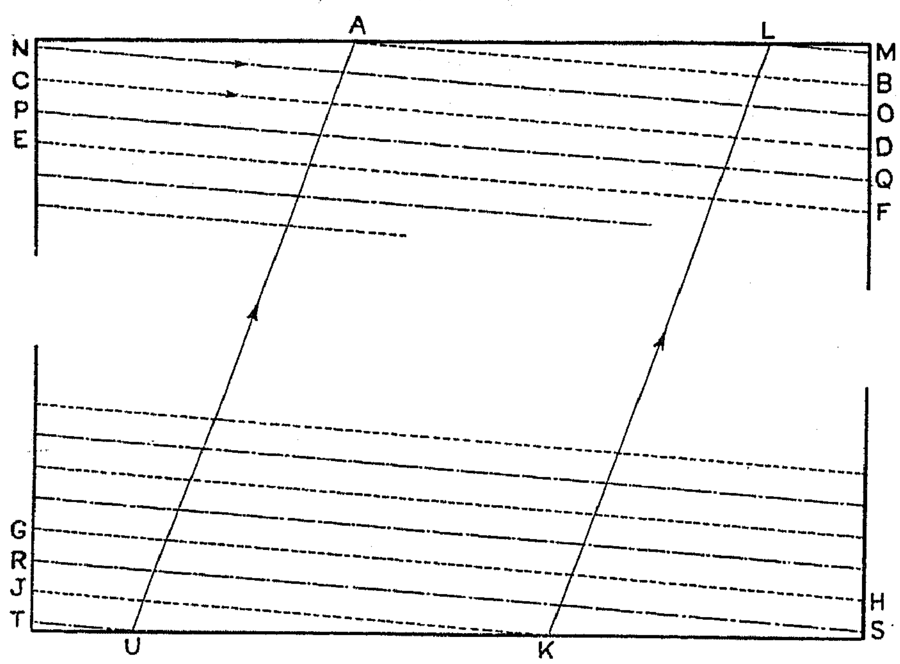

Fig. 2.—Diagram of interlaced scanning.

From the foregoing it will be seen that the complete picture is scanned in two frames, but as each frame contains an integral number of lines, plus a half, the two frames will interlace. The system does not require the short return-times shown for the line and frame scans, nor need the lines begin in the positions shown. Provided the line and frame traversals are regularly recurrent and have the correct frequency ratio (2 frames = odd number of lines), an interlaced picture will be obtained.

PART II

VISION INPUT EQUIPMENT

By C. O. BROWNE, B.Sc.

(*First received* 1*st December*, 1937, *and in final form* 12*th March*, 1938.)

SUMMARY

Television equipment, in particular that supplied to the B.B.C. for the London Television Station, is described, and the technical considerations which led to its development are outlined. A description is given of the purpose and practical design of the apparatus handling modulation frequencies, which comprises studio equipment, camera control equipment, modulation amplifiers for the radio transmitter, and associated apparatus.

Owing to the large amount of equipment covered by these headings, little more than cursory descriptions can be included, making it imperative to omit many details of design. References are therefore made to the relevant patent specifications, from which more detailed information may be gathered.

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(1) INTRODUCTION

The specification of wave-form adopted by the Marconi-E.M.I. Television Co. includes a number of fundamental conditions which are basic, and which must be satisfied whatever the form of the television equipment. Apart from the question of the number of lines and frames, the equipment must be capable of meeting the demands of the d.c. system of transmission as defined in Part I of this paper.

The form of the television equipment is largely defined by the choice of a method of scanning the picture, and much experimental work had been done in the laboratories of Electric and Musical industries, Ltd., on both mechanical and electrical methods of scanning before the Emitron camera was eventually evolved. Although good pictures were obtained using Emitron cameras as early as 1934, the signals derived from these cameras possessed certain peculiarities not met with in mechanical scanning equipment. Considerable development work was necessary before these cameras could form part of equipment in which the basic desiderata of the wave-form specification are recognized. Once these difficulties had been overcome, it was possible to take advantage of the facilities and flexibility afforded by the Emitron cameras in laying down equipment for practicable transmission of television programmes.

A full-scale studio equipment answering the requirements for a television service was completed in the spring of 1935, and was, apart from a number of small improvements, essentially the same in fundamental design as the equipments installed at the London Television Station and in the mobile television scanning van which was subsequently constructed for outside broadcasts. A particular form of modulation amplifier was developed to meet the specific requirements of radiated power of the transmitter for the London Television Station.

(2) GENERAL LAYOUT

The extent of the studio and camera control apparatus was influenced considerably by the requirements of programme production, and the general layout of the equipment evolved is shown in schematic form in Fig. 3.

In order to provide flexibility for studio productions a number of cameras are required, giving the producer the facility to add variety to his camera viewing-points without actually moving the cameras. Six camera channels are provided, of which any two may be used in conjunction with two film projectors for the presentation of a continuous programme of film. The circuits of all the camera channels are identical and the channels are therefore interchangeable; an unquestionable advantage in circumstances of emergency caused by a breakdown.

It is necessary that the programme producer should be able to see not only the picture from the camera channel which is connected to the radio transmitter, but also the pictures scanned by any of the remaining five cameras. In order to curtail the extent of the control apparatus, a compromise is made, in that the camera fading is arranged after the " A " amplifiers, and the succeeding equipment required for producing pictures is constructed only in triplicate. The fading mixer is remotely controlled, and has three independent output circuits which lead to the three picture channels; one of these is connected to the line to the radio transmitter, and the other two are available for monitoring pictures from any of the remaining five camera channels.

A further requirement is that all cameras should be synchronized, so enabling the producer to fade from one picture to another without resorting to a change-over of synchronizing signals. An added advantage accrues from this arrangement in that two or more pictures may be superimposed if required. This demand necessitates that the scanning circuits of the cameras, and also the various pulses required for the development of the picture and synchronizing signals, should be timed from a master oscillator. It is preferable that the latter should, in turn, be controlled in frequency by the frequency of the supply mains. Summarizing, in the feeder from the control equipment to the radio transmitter there is a continuous train of synchronizing signals; and picture signals, originating in any of the camera channels, are inserted accurately in the appropriate intervals between synchronizing-signal pulses.

As the modulation amplifiers are closely associated with the radio transmitter they should perhaps be visualized as part of the transmitter equipment. The transmitter would in general be in a location remote from the camera control equipment (many miles in the case of a television outside broadcast), so that it was considered important that there should be one channel only connecting control equipment to modulation amplifiers. This channel should transmit television signals, which, apart from the relative amplitudes of the picture and synchronizing signals, should conform with the wave-form specification. The modulation amplifiers magnify these signals, preserving their d.c. characteristics, and modulate the carrier of the radio transmitter.

(3) STUDIO EQUIPMENT

Cameras

In order to leave as much free space as possible in the studio for the handling of scenery, lighting, and so on,

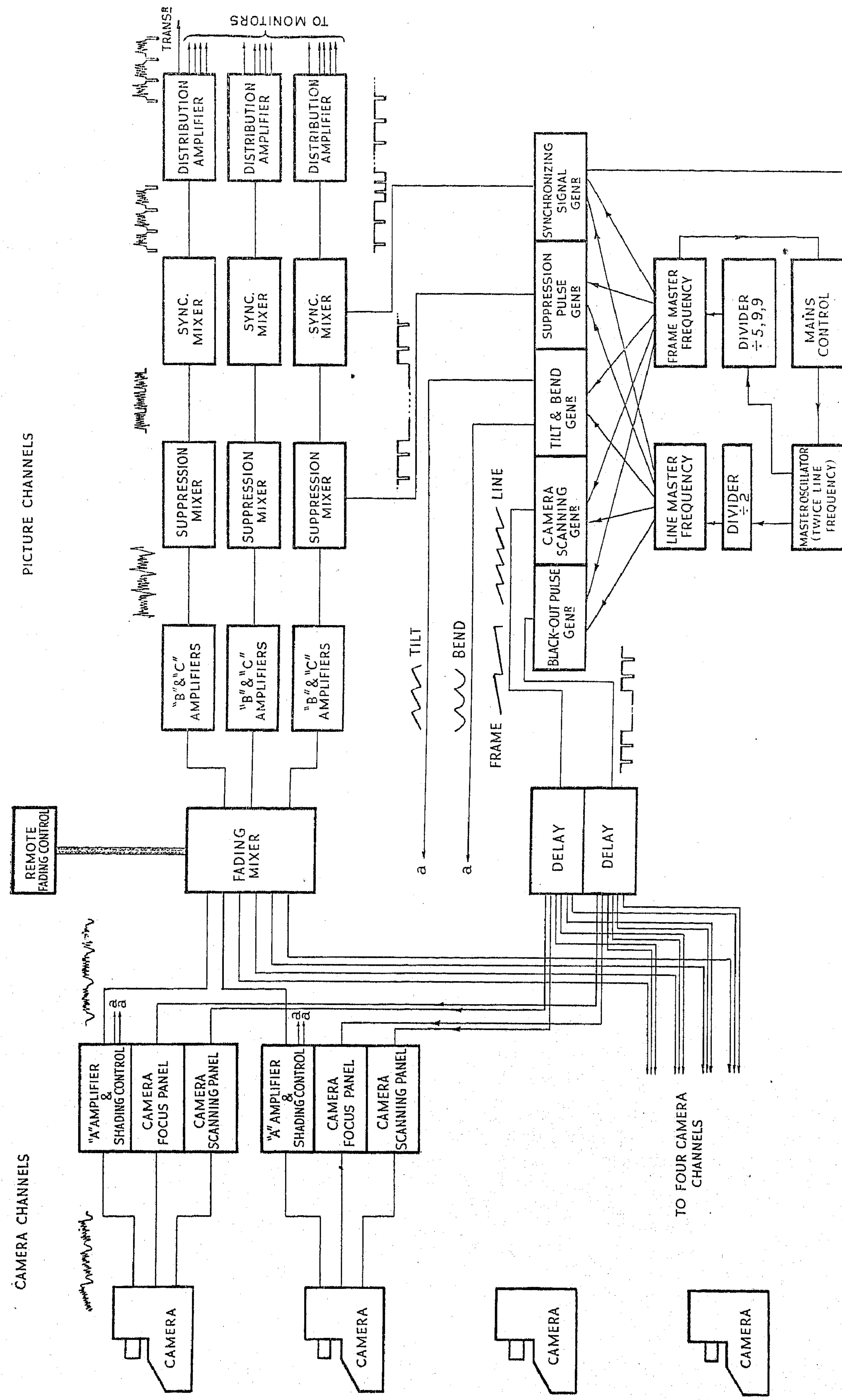


Fig. 3.—Schematic layout for control equipment of 6-camera and 3-picture channels.

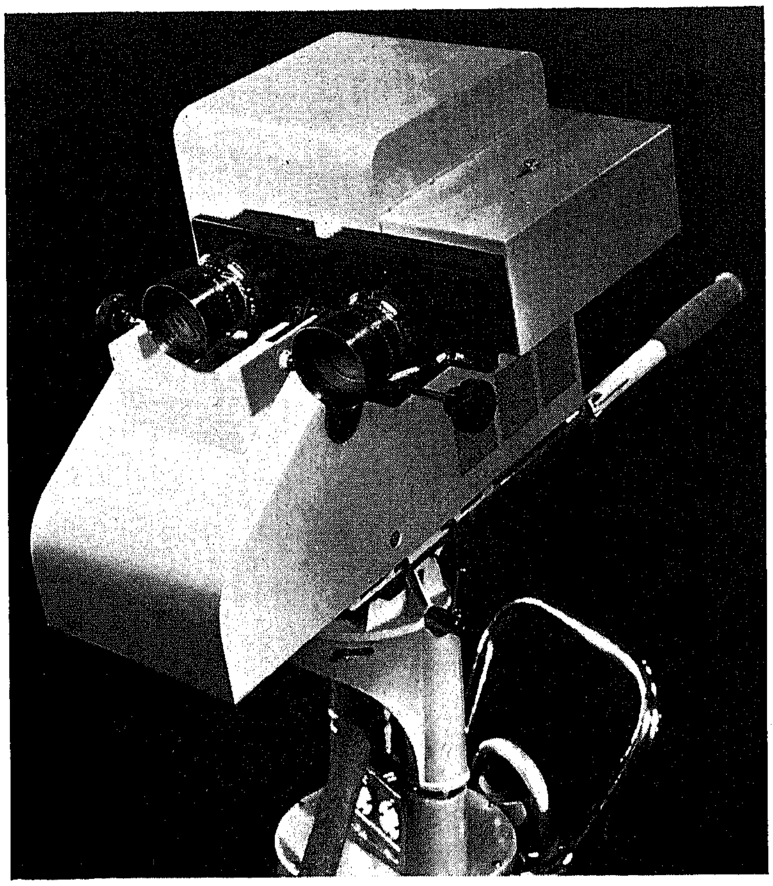


Fig. 4.—Emitron camera.

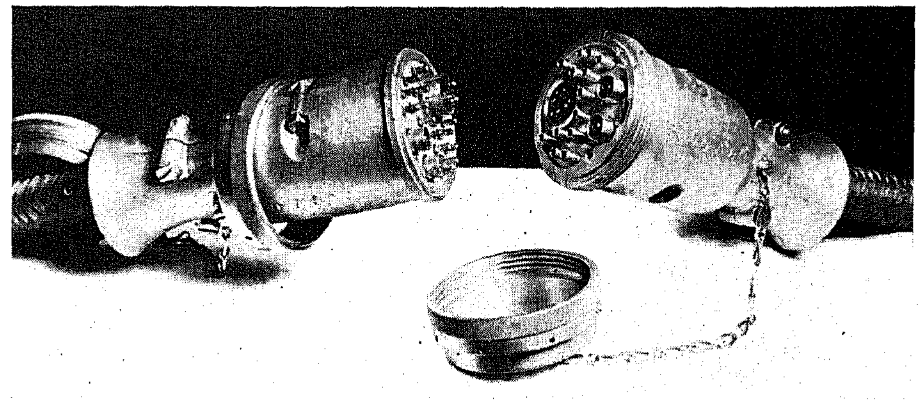


Fig. 6.—Camera-cable connector.

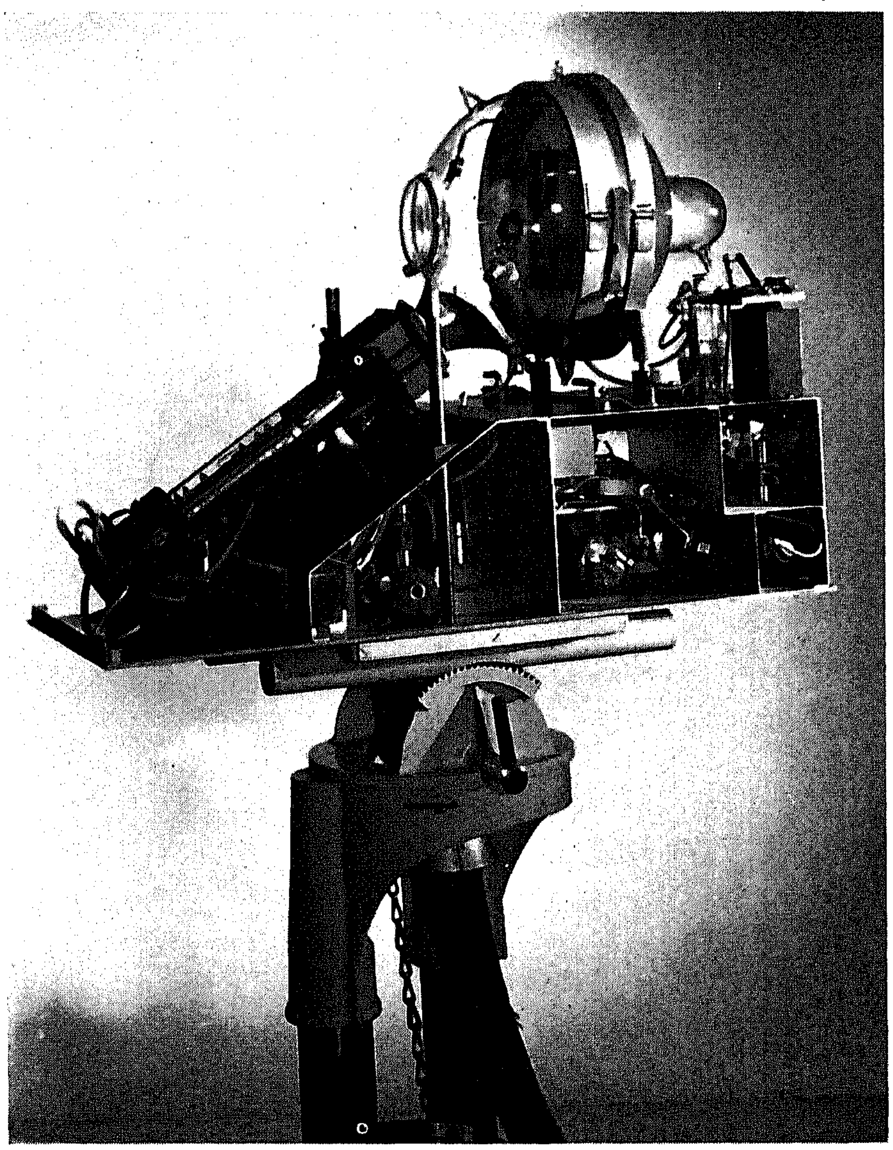


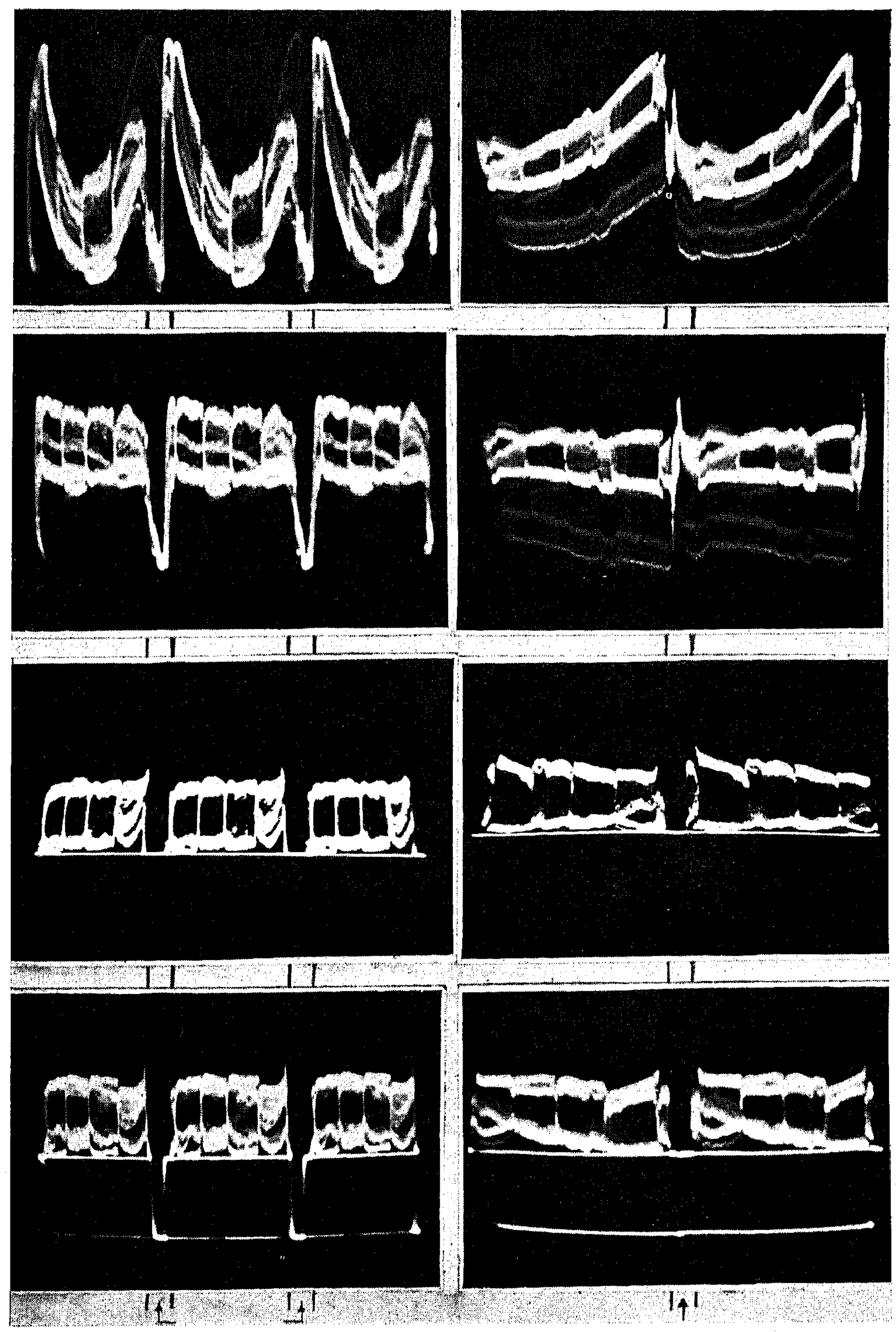
Fig. 5.—Emitron camera (cover removed).

(*a*)

(*b*)

(*c*)

(*d*)



Intervals between lines (line scan) Interval between frames (frame scan)

Fig. 7.—Development of television-signal wave-form.

(*Facing page* 768)

Plate 2

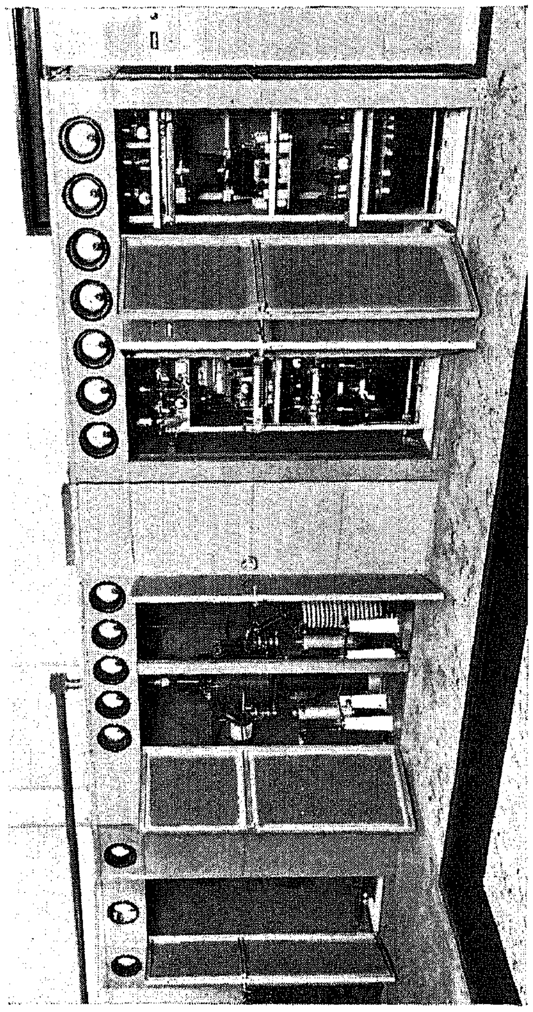


Fig. 14.—Modulation amplifiers.

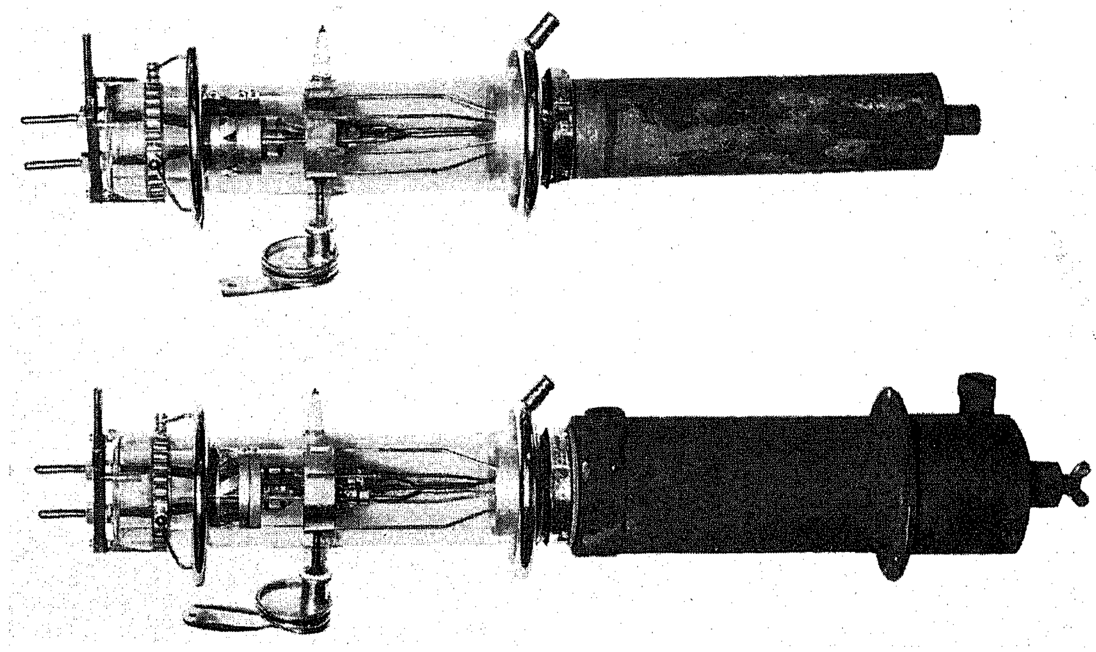


Fig. 21.—Transmitting valve, type C.A.T.9.

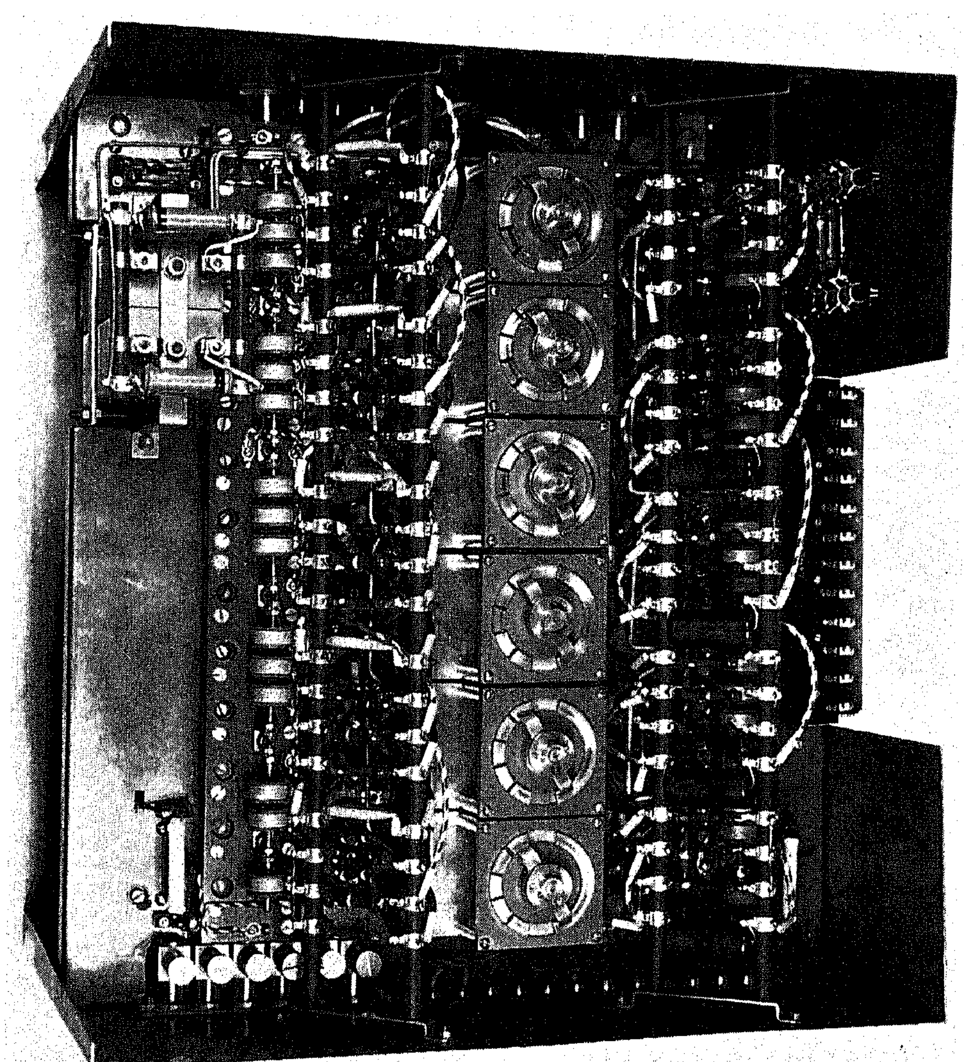


Fig. 9.—Camera delay panel.

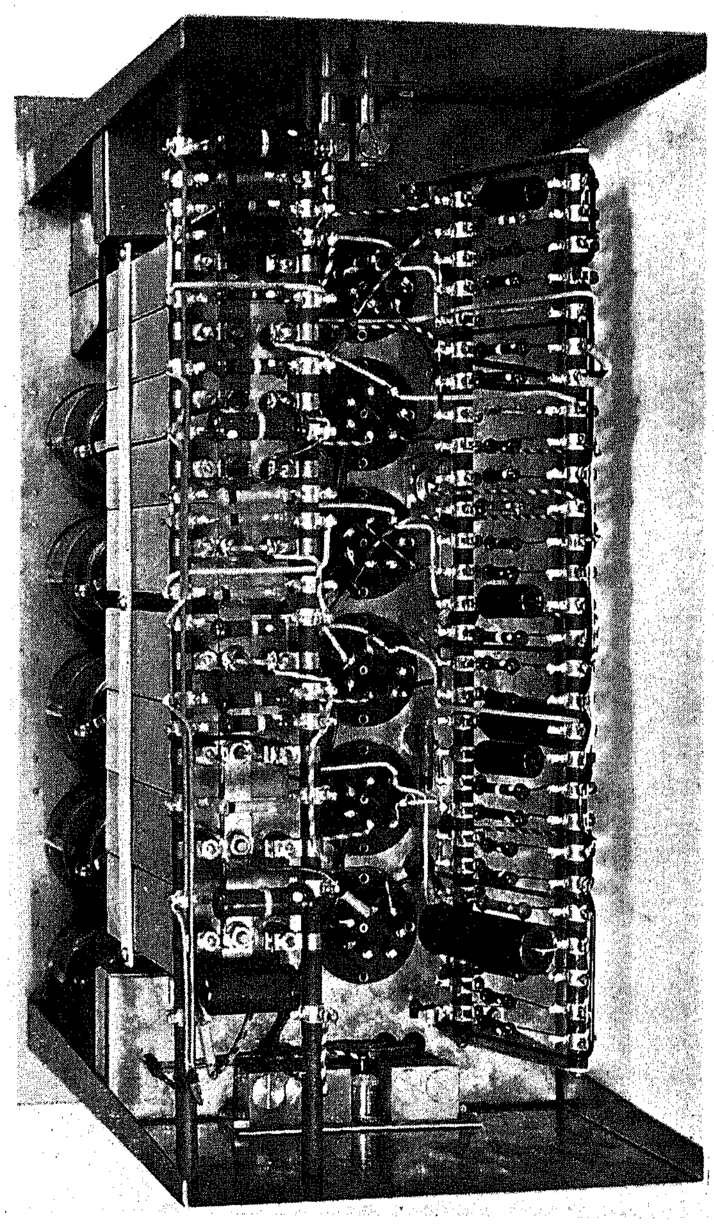


Fig. 10.—Artificial-signal generator.

each camera is designed as a unit to which the supplies are carried by a single cable from the camera control equipment, which would in general be housed exterior to the studio.

Each camera carries, apart from the Emitron tube itself, an optical system and view-finder, and a head amplifier. The optical system consists of a main lens which forms an image of the scene to be transmitted on the mosaic screen. Coupled to the main lens is a similar lens of the viewfinder which forms a duplicate image on a ground-glass screen having the same dimensions as the mosaic, and which is observed by the camera operator. Automatic compensation for parallax is provided so that the centre of the viewfinder image corresponds to the centre of the transmitted picture for all distances of the object in focus from close-up to infinity. The complete camera is shown in Fig. 4 (see Plate 1, facing page 768) with a pair of 12-in. telephoto lenses having a maximum aperture of $f/4 \cdot 5$. For general purposes two 6·5-in. $f/3$ lenses are used, this focal length being the shortest permitted by the construction of the Emitron tube itself. The width of the mosaic is 4·75 in., enabling a viewing angle of 40° to be subtended when the 6·5-in. lens is focused to infinity.

The head amplifier contains four valves; the grid of the first valve is connected to the signal plate of the Emitron tube, and is used as a cathode follower. (As the cathode follower is used frequently throughout both control equipment and modulation amplifiers, the advantages of this circuit have been made the subject of Appendix 1.) The cathode of the first valve is connected to the ring surrounding the signal-plate visible in Fig. 5 (Plate 1), so that its variations in potential are in phase with the potential-changes of the signal plate, and in consequence the capacitance of the input circuit is effectively reduced from 16 $\mu\mu$F (ring disconnected) to 12 $\mu\mu$F. The amplitude of picture signals as generated in the input circuit is made as high as possible relative to ground noise, by ascribing a large value to the input resistance, with subsequent compensation in the "A" amplifiers for the losses in higher frequencies involved.* The reduction in input capacitance enables a larger load-resistance to be used for the same amount of frequency correction. An additional boost of the lower frequencies, as generated by the Emitron tube, is also included in order to override irregularities introduced by valve flicker or microphonic noises generated when the camera is being handled. The second and third valves of the head amplifier serve to amplify the signals, and the last stage is another cathode-follower which feeds into a flexible feeder contained in the camera cable.

Camera Cable

In addition to the feeder mentioned above, the camera cable also contains a second flexible feeder, through which negative pulses at line and frame frequencies are applied to the grid of the Emitron tube to shut off the cathode-ray beam during the flyback intervals. Each feeder consists of a fine cadmium-bronze conductor crinkled so that it is approximately supported by point contact only from the surrounding gutta-percha tube, which in turn is covered by a braiding of copper wire. The crinkled construction is effective in reducing losses in the dielectric, and as the inner conductor is definitely located the capacitance per unit length is comparatively uniform. The remainder of the conductors in the cable (of which a connector is shown in Fig. 6, Plate 1) supply voltages for the head amplifier, potentials for the Emitron tube, and the sawtooth currents for the deflecting scanning-magnets surrounding the neck of the tube. Coverings of wire braid, rubber tape, and an overall coating of cord braid finish the camera cable, rendering it waterproof and substantially impervious to electrical interference.

* See Reference (1).

(4) CAMERA CONTROL EQUIPMENT

The camera control equipment may be divided into four main groups, comprising camera channels, picture channels, pulse generators, and supply equipment. The descriptive matter which follows relating to the camera control equipment should be read with particular reference to Fig. 3, which indicates diagrammatically the progress of development of the television signals.

Each camera channel contains a unit for focusing the cathode-ray beam of the Emitron tube, by which the correct potentials may be adjusted for the electrodes. This unit also contains controls for adjusting the beam current for optimum working; a reflecting galvanometer facilitating this operation. A relay disconnects all dangerous voltages from the camera cable if for any reason the scanning currents should cease to flow, e.g. owing to the inadvertent breaking of a camera-cable connection. Another unit is included in each camera channel which accepts sawtooth signals from the pulse generator, and drives scanning currents at line and frame frequencies into the deflection coils in the camera. This unit has controls affecting the height and width of the scanned area, and for shifting the scanned area bodily.

Picture Signals

Apart from the distortions of the picture signals which are deliberately introduced in the head amplifier, the signals from the camera also contain spurious signals originating in the Emitron tube, of which the character depends largely upon the illumination of the scene being transmitted. These spurious signals occur during both forward and flyback periods at line and frame frequencies. The effect of the forward-period spurious signals is generally an overall "tilt" of the picture signals in a line or frame scan, or an overall "bend," or the effect may be a mixture of both "tilt" and "bend." Further, the "tilt" and "bend" may occur in either sense. The signals photographed in Fig. 7 (Plate 1) are typical of those produced by a scene situated in a field of very poor illumination; Fig 7(*a*) showing the signals received from the camera after magnification in the "A," "B," and "C" amplifiers.

Fortunately, under conditions of fair illumination, the "tilt" and "bend" signals conform to a shape which can be balanced by a simple means consisting of artificial shading signals manufactured in the group of pulse generators, of which the "tilt" and "bend" components can be adjusted both in amplitude and in sense by a small number of controls. Fig. 7(*b*) shows the picture signals after the introduction of artificial shading signals containing "tilt" and "bend" components.

In circumstances of poor illumination the spurious signals contain components which cannot be balanced by means of simple shading wave-forms, with the result that under these conditions the remnant of uncompensated spurious signals appear as white or dark patches in parts of the picture.

As the character of the spurious signals is likely to be different in the various camera channels, it is obviously necessary to provide independent shading controls. In each " A " amplifier, to which the picture signals from the appropriate camera are taken, four controls are therefore provided by which the amounts of artificial " tilt " and " bend " signals at both line and frame frequencies may be adjusted.

The spurious signals which occur in the flyback periods are of a more erratic nature, their shapes depending upon a variety of circumstances. Since the scanning currents are synchronized, however, these spurious signals may be suppressed, preparatory to the introduction of the synchronizing signals, in the same manner for all camera channels. It is convenient to remove them later on in the picture channels, and the description of the process involved is therefore included in the description of the picture channels under the heading " Interval Suppression."

Fading Mixer

The outputs of the camera channels are taken to a mixing unit of which the controls are remotely situated with the producer. The circuit of this unit provides that any of the six input signals may be faded at will to either of three output terminals connected to the picture channels. Groups of six variable-mu valves are incorporated having a common anode circuit to each group, and each camera channel is connected to a circuit containing the grids connected in parallel of one valve from each group. The valves are normally backed off, but are brought into an operating condition when the remote potentiometers are manipulated.

(5) PICTURE CHANNELS

The signals from the output of the fading mixer are amplified by a " B " amplifier having adjustable gain, with maximum voltage-magnification of 150 times, and a " C " amplifier with fixed magnification of 20 times. Couplings between stages in these amplifiers follow transmission-line practice, in that the capacitance of the anode circuit of one stage is separated from the capacitance of the following grid circuit by a series inductance.

Following the " C " amplifier, a unit is included in which the intervals between lines and frames are " cleaned up " in readiness for the introduction of the synchronizing signals. As described in Part I, the level during these intervals represents the dividing line between picture and synchronizing signals; so, besides introducing the cleaning-up process, the suppression mixer introduces the direct component into the picture signal.

D.C. Insertion

The insertion of the d.c. component into a train of picture signals implies that the signal corresponding to picture black is established at a definite potential. This condition may usually be achieved by a cumulative process from a series of recurrent signals corresponding to black. Negative picture signals (" white " signals are more negative than " black ") are impressed upon the grid of a valve through a series condenser with a leak to earth, and are of such amplitude that grid current flows at the black (positive) signals. The grid current progressively charges the condenser, until a state is reached in which the charge acquired is balanced by the discharge of the condenser by the resistance leak to earth.

As the negative picture signals from the output of the " C " amplifier still contain spurious signals between lines and frames, which may be variably more positive than those corresponding to picture black, the cumulative process outlined above will not establish a definite potential corresponding to black. The charging current for the condenser is therefore arranged to be derived, not from grid current, but from the anode of an auxiliary valve rectifier connected from the grid of the valve to earth. Pulses are applied to the grid of this rectifier which render it inoperative during the intervals between lines and frames, so that the picture-signal amplitudes are referenced from the " blackest " signal derived from the picture.* It will be appreciated that this arrangement is in some respects a compromise, because the blackest part of every picture will not invariably reflect the same (or zero) light, but it does ensure in addition that in the subsequent circuits the picture signals are handled without amplitude distortion, and without extending below " picture black " level into the region allocated for the excursions of the synchronizing signals.

Interval Suppression

The picture signals having been referenced from black, the spurious signals are suppressed by adding large positive pulses to the negative picture signals during the intervals between lines and frames.* The pulses lift the spurious signals clear of the picture signals in the infra-black direction, and the spurious signals are removed by rectification at a subsequent valve. This valve is provided with a bias control, by which the level at which the suppression pulses are cut off can be adjusted to be the same as that of picture black. Fig. 7(*c*) (Plate 1) shows picture signals to which this process has been applied.

Synchronizing-Signal Mixer

The picture signals are now free from spurious signals and contain a direct component. In the following unit the synchronizing signals are added to the " prepared " intervals between lines and frames, and appear as in Fig. 7(*d*). The television signals are now ready for radiation, except for the relative amplitudes of picture and synchronizing signals. It will be explained that, as the modulation amplifiers limit the amplitude of synchronizing signals, it is usual to maintain unity ratio between the amplitudes of synchronizing and picture signals from the control equipment.

Distribution

Each picture channel is terminated by a distribution amplifier from which five lines radiate. The circuit of this amplifier comprises cathode-follower valves of which

* See Reference (2).

the grids are fed in parallel with the picture signals; these valves feed the modulation amplifiers of the radio transmitter, monitoring points, etc.

(6) MASTER-FREQUENCY GENERATORS

The main requirements of the master-frequency generators are that there should be accurately $202\frac{1}{2}$ line-timing signals per frame-timing signal, and that the frame signals should be in synchronism with the supply mains (50 cycles per sec.). A master oscillator operating at twice line frequency (20 250 cycles per sec.) is provided, and its frequency is divided down by " counter " circuits to the frame frequency.* The master oscillator is of the multivibrator type, and is such that its frequency can be controlled to a limited extent by variation of the bias on one of the valves. The derived frame-frequency pulses are added to the sloping portion of sine waves taken from the mains, so that the instantaneous amplitude of the combined signals at the occurrence of frame pulses will vary if the latter tend to depart in phase from the mains. The amplitude variations are separated by a rectifier which provides bias for the master-oscillator circuit, thereby controlling the master frequency, so that, when divided, the frame frequency is equal to the frequency of the mains.

In the " counter " circuits referred to above, a condenser is included which is charged to an increasing potential by successive pulses, and the potential is arranged to be sufficient to " trigger " a multivibrator circuit, associated with the condenser, after a given number of pulses. The circuit immediately discharges the condenser to its initial state, and pulses are derived from the discharges which can then be divided in a further counter circuit, and so on. In the case of the line frequency it is only necessary to divide the master frequency by 2, but in order to obtain the frame frequency the master frequency is divided successively by 5, 9, and 9.

* See Reference (3).

Mechanical Master-Frequency Generator

The action of the mains-frequency control circuit of the master oscillator is comparatively fast, and in consequence rapid changes of phase of the mains are reproduced in the television signals. Since these signals are all accurately inter-related, this is of no consequence when a cathode-ray receiver is being used, but a mechanical receiver possessing considerable inertia would be unable to follow quick changes in phase. As an alternative to the electrical oscillators, a mechanical master-frequency generator has therefore been used which generates a twice-line master frequency and frame frequency. This machine (shown in section in Fig. 8) is driven synchronously with the mains at 3 000 r.p.m. through a mechanical filter, and is of a capacitance-inductor type having 405 poles on both rotor (1) and stator (2), with a single pole (3) rigidly attached to the rotor for generating the frame-frequency timing pulse. In its construction the rotor was built up from laminations, all of which were cut simultaneously, and on assembly the laminations were rotated through an angle with respect to one another and bolted together. The same process was adopted in respect of the stator, and by this means repetitive errors, due to irregular spacing of the poles, have been reduced to a negligible quantity.

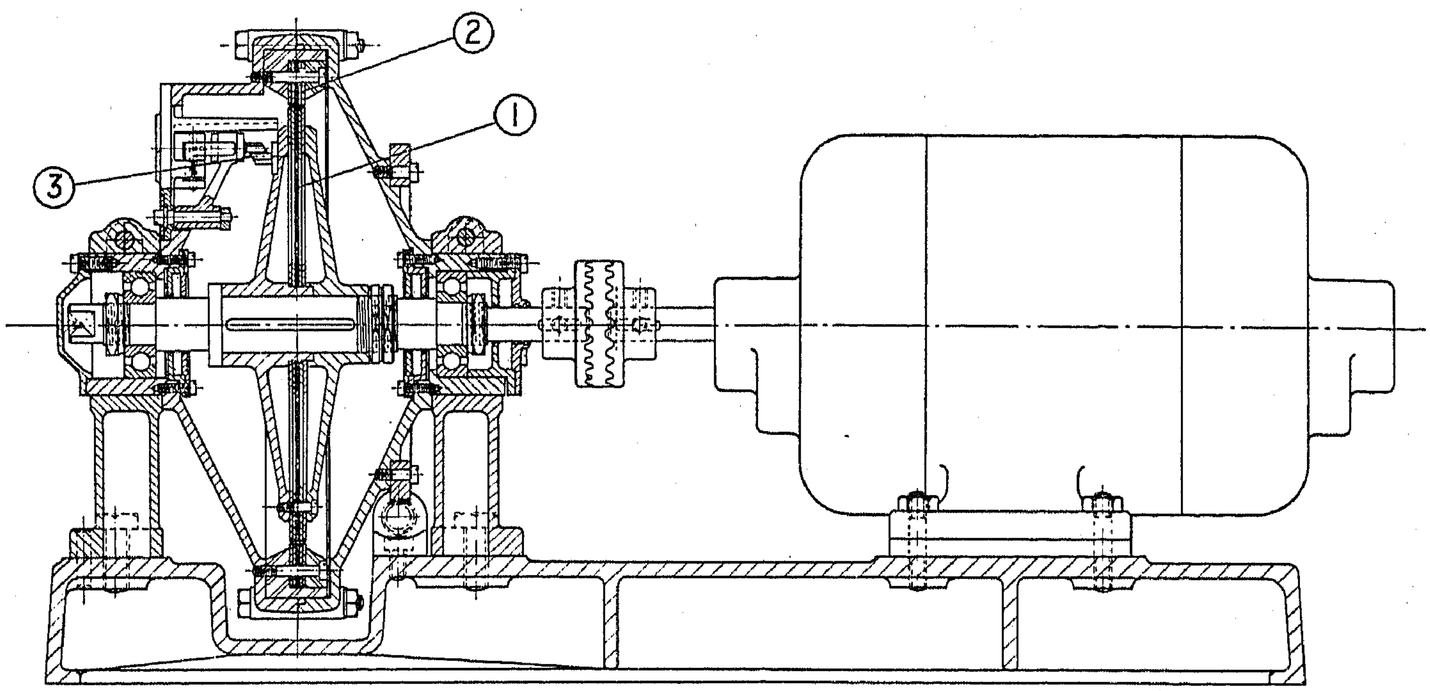


Fig. 8.—Master-frequency generator.

The master frequencies are fed to the units they control through adjustable delay circuits, in order that the various pulses shall be given the correct relative positions in the train of television signals. The time taken for signals to travel over a long length of camera cable is appreciable, and therefore a variable delay operated by a switch is provided by which the timing of the line-scanning currents can be adjusted to suit the length of cable in use. This switch also adjusts the heater currents of the camera-head amplifier, and the timing of the black-out pulses for the Emitron tube.

(7) PULSE AND WAVE-FORM GENERATORS

During the course of development of the television signals from the camera to the distribution amplifier, a

variety of pulses and wave-forms are required which must be synchronized from the master frequencies. These artificial signals are derived from a group of "pulse generator" panels, which are required to supply "black-out" signals for the Emitron tube in the cameras and "suppression" pulses for removing spurious signals, and also to generate synchronizing signals. Each of these trains of signals is composed of pulses at line frequency, and in some cases pulses at frame frequency are introduced at the appropriate instant; multivibrator circuits being used for the generation of the pulses, which may be cleaned up by limiting the amplitude in both positive and negative senses.*

As it should be assumed that the receivers will rely on the accurate formation of synchronizing signals from the transmitter to enable good interlaced scanning to be obtained, considerable trouble has been taken to ensure that the timing of synchronizing signals is correct. The narrow pulses of the line-synchronizing signals and the broad pulses constituting a frame-synchronizing signal are applied respectively to the grids of two hexode valves; the latter being alternately switched into an operative condition by means of a control pulse of appropriate duration at frame frequency. An interlocking circuit involving further hexode valves is used to ensure that the change-over from line pulses to frame pulses is initiated by the simultaneous occurrence of an interval between broad pulses and a master frame-frequency pulse.†

It is convenient in the control equipment to have available a source of standard television signals, by means of which the levels of the transmitted signals may be set up. Suitable signals are produced by pulse generators, and constitute a black rectangular cross superimposed on a white background of peak amplitude; this artificial signal being mixed with the synchronizing signals in the picture channel. The wave-front of the vertical bar of the artificial signal as generated by the multivibrator circuits is comparatively sharp, and the reproduction of this wave-front on a receiver screen, or signal monitor, provides a good criterion of the efficiency by which the higher frequencies are being transmitted. An indication of the response at the lower frequencies of the system, or part of it, is afforded by the horizontal bar, while the d.c. conditions may be examined by noting any change in black level when the artificial signals are switched off.

Included in the pulse-generator group is a number of wave-form generators. Of these, one is necessary for the supply of the sawtooth signals at both line and frame frequency which are used to produce currents for the magnetic deflecting system of the Emitron tubes. As the gun in the Emitron tube is not normal to the plane of the mosaic, the area scanned on an imaginary plane perpendicular to the axis of the gun should have a keystone appearance: a condition which is achieved by modulating the amplitude of the line deflection by the frame deflection.‡ But, in addition, a uniform angular velocity of the beam in the frame direction would produce an uneven separation of the lines on the mosaic, so that a further correction is introduced to compensate for the distortion which would otherwise be present due to this cause. Even so, by consideration of the solid geometry of the disposition of the elements in the Emitron tube it will be seen that the scanned area on the mosaic screen will be subject to "pincushion distortion." This is corrected in the camera itself by suitably designing the scanning coils so as to scan a rectilinear image on the plane of the mosaic.*

* See Reference (4). † *Ibid.*, (5). ‡ *Ibid.*, (6).

Other wave-form generators are wanted for the generation of "tilt" and "bend" signals at line and frame frequencies. The "tilt" signals are derived from the growth of potential of a condenser charged through a resistance; the condenser being discharged by appropriate pulses at line or frame frequency. The "bend" signals are obtained by an integration process of the "tilt" signals.† The outputs of both "tilt" and "bend" are symmetrical about earth, so that the control potentiometers on the "A" amplifiers have signals of opposite sense at each end, with a position of zero signal at the centre.

(8) FILM TRANSMITTERS

Two film transmitters are required in order that a continuous programme of film may be radiated if desired. These machines are standard theatre projectors as manufactured by the British Thomson-Houston Co. and are adapted to be used in conjunction with Emitron cameras with a suitable optical system and synchronous shutter. The projectors are of the intermittent type, in which the film is stationary in the gate for approximately 75 % of a complete picture-cycle ($\frac{1}{25}$ sec.), and a shutter driven by a synchronous motor is fitted, by which an image of the film is projected into the camera twice during the stationary period. The exposure of the mosaic occurs within the intervals between successive frames of the television signals, and the latent electrical image developed on the mosaic is scanned under conditions of no illumination. At the commencement of a transmission the phase of the master frame-frequency generator is adjusted to that of the shutter motors; the latter being left to run continuously during the transmission.

(9) SUPPLIES

To complete the description of the camera control equipment, some mention should be made of the supplies. Except for a small number of dry batteries which supply voltage only, mainly for control purposes, the equipment is entirely mains-operated. A number of separate high-tension rectifiers are used with independent smoothing circuits, and their outputs are stabilized by circuits which are an adaptation of the cathode-follower circuit (Appendix 1). Valves are provided in the cathode circuits of which the various loads are connected, and the required H.T. voltage is controlled by means of a battery connected between the grids of the stabilizing valves and earth. The stabilizers reduce the effective impedance of the H.T. supply in addition to diminishing irregularities and ripple from the rectifiers, and, because some variation in voltage persists due to fluctuations in mains voltage, additional circuits are included which amplify the fluctuations and re-introduce them into the grid circuits, so that the original variations tend to be neutralized.‡

The L.T. supplies are mainly alternating current, but

* See Reference (7). † *Ibid.*, (8). ‡ *Ibid.*, (9).

where direct current is necessary, i.e. in the case of the head amplifiers, copper-oxide rectifiers and smoothing circuits are provided.

(10) GENERAL CONSTRUCTION OF THE CAMERA CONTROL EQUIPMENT

All the units comprised in the control equipment are constructed in 19-in. panels, and fit into telephone racks of standard size. Considerable attention had to be paid to ventilation, in view of the large number of valves which are required (approximately 500, including rectifiers), and since it had been found that when amplifiers are worked under conditions of excessive temperature their characteristics vary considerably. In all units the valves are enclosed in a space immediately behind the front panel, otherwise devoid of components, so that when the units are mounted adjacent to one another in a rack a vertical passage is formed which is ventilated by a convection process. In some cases it has been advantageous to assist the ventilation by means of fans mounted at the top of the racks. The general form of construction and layout can be seen from Plate 2 (Fig. 9, camera delay panel; and Fig. 10, artificial-signal generator). These photographs show the back of the panels with the cover off. The panel nearest the observer is the sub-panel, the ventilating duct being between this sub-panel and the front panel.

In view of the possibility that cameras and camera control equipment might be operating in close proximity to the sound and vision aerials, where the field strength would be inordinately high, it was advisable to include radio-frequency rejector circuits, tuned to a frequency between sound and vision carriers, in the supplies to each unit where necessary. In addition, minute circuits, having low capacitance, were developed for the suppression of radio frequency at the grids of certain valves. The overall effect of the radio-frequency suppression is that a camera may be taken close to the aerials themselves, without traces of feed-back being apparent.

(11) PERFORMANCE OF THE STUDIO AND CONTROL EQUIPMENT

The maximum sensitivity of the equipment is limited by the ground noise from the amplifiers, and also by the shape of the "tilt" and "bend" spurious signals. With an average Emitron tube issued for programme service, satisfactory pictures can be obtained with an illumination of 130 foot-candles or 1 400 lux, and good pictures are easily obtainable with 200 foot-candles or 2 160 lux. This means that pictures can be transmitted in any reasonable condition of daylight; a dull day presenting about 200 foot-candles. Pictures can be obtained with as little illumination as 50 foot-candles, but would, of course, be somewhat marred by the defects mentioned above.

In order to meet the 2·5-Mc./sec. frequency and phase characteristics which a 405/50 system demands, each unit was designed to extend to a minimum of 3·5 Mc./sec., and on calibration was adjusted to have a maximum droop of 0·5 db. at this frequency. As there is a large number of units effectively in series, a maximum departure from a level characteristic of 0·1 db. was allowed before the unit commenced to cut off. In addition to the calibration of individual units an overall calibration of the equipment was made. This calibration would reveal traces of feedback if the overall calibration was not that expected from the sum of the calibrations of individual units. Feedback might be due to the physical disposition of components of the apparatus, but was usually indirectly due to the earthing system, which, owing to the quantity of apparatus involved, is inclined to assume long dimensions.

Tests were made on the "resolving power" of the equipment at the London Television Station by erecting screens on which a number of lines of known spacing were ruled at a given distance from a camera, and the result showed that 240 black lines separated by equal white spaces could be resolved when the whole width of the mosaic was in use. The standard of excellence of the focus of the cathode-ray beam of the Emitron tube is more than adequate, practical tests showing that the latest tubes are capable of resolving more than 1 000 lines.

Further tests were made on the efficiency of interlaced scanning by transmitting an inclined edge, and examining the monitor picture with an extended frame-scan. The results of these tests showed that each line contributes to the detail of the picture, and that the traces of the cathode ray on the mosaic of the Emitron transmitting tube were accurately interlaced.

(12) MODULATION AMPLIFIERS

General Requirements

It has already been pointed out that a single channel only connects the camera control equipment (which may be located either close to the radio transmitters, or remote in the case of an outside broadcast) with the modulation amplifiers of the radio transmitter. This channel carries television signals which are complete in themselves, in which a definite potential corresponds to the "black" level dividing-line between the picture and synchronizing signals, and it is the purpose of the modulation amplifiers to magnify these signals, preserving their d.c. characteristics, and to apply them to the grids of the final stage of the radio transmitter.

In Part I of this paper the point was stressed that the carrier should be reduced to zero during the transmission of synchronizing signals, and sufficient signal must therefore be applied to the transmitter to carry the grid potential beyond cut-off. The television signals applied to the input of the modulation amplifiers are usually adjusted as nearly as possible to contain equal amplitudes of picture and synchronizing signals, but owing to the curvature of the transmitter characteristic in the region approaching cut-off the radiated synchronizing signals are reduced in amplitude with respect to the picture signals.

The ratio of picture and synchronizing signals mentioned above is approximate only, because it is obvious that frequently the ratio may be disturbed by circumstances beyond the control of the operators of the equipment. Variations in synchronizing amplitude which might cause variations of black level would be likely in cases in which the signals were received over long lengths of cable or by radio link from the camera control equipment. Constancy of black level is a fundamental requirement of the system, and means are therefore provided, in the modulation amplifiers, by which the output

potential corresponding to black level is automatically maintained at a predetermined value irrespective of considerable variations of the incoming synchronizing-signal amplitude.

In consequence, two controls are necessary to adjust the working conditions of the modulation amplifier, in order that the wave-form as radiated from the transmitter shall conform with the stipulation as to picture-signal/synchronizing-signal ratio. By means of the first of these controls the potential in the final circuit is adjusted so that black level produces 30 % of the voltage amplitude of carrier corresponding to peak picture; then the second control is operated by which the magnification of the amplifiers is adjusted until the transmitter is adequately modulated.

Other requirements of modulator amplifiers may be summarized as follows:—

(i) The final stage of the radio transmitter is grid-modulated, and requires a complete excursion of approximately 2 000 volts to cut off the carrier at one extreme, and to produce maximum carrier at the other. As the signals from the control equipment are transmitted with a minimum amplitude-difference of 10 volts (overall) from tips of synchronizing signals to peak of picture signals, the voltage magnification of the modulator amplifiers must be of the order of 200 times.

(ii) The amplitudes of the picture and synchronizing signals applied to the radio transmitter are approximately equal, so that the amplifiers are called upon to change the potential of the transmitter grids by 1 000 volts in the maximum period of 0·2 microsec. demanded by the picture detail of the system. The input capacitance of the transmitter, including the connecting line from the modulators, is about 400 $\mu\mu$F, so that the final stage of the modulators must be capable of delivering at least 2 amperes to charge the input capacitance over the amplitude range occupied by picture signals.

(iii) In order to radiate a signal in which the d.c. components are preserved, it is necessary that, after having charged the input capacitance to a given potential, the modulators should be capable of maintaining this potential indefinitely. The preceding condition, together with this stipulation, at once determines the power-handling capacity of the final stage of the modulation amplifiers. In addition, it becomes obvious that special attention has to be paid to the amplifier design, including the H.T. supply circuits, in order that there shall be no falling-away of potential over an extended period.

In a 405/50 television system the picture-element frequency is approximately 2·5 Mc./sec., and the modulation amplifiers are therefore designed to transmit a level characteristic up to this frequency. In order to prevent violent phase-changes towards the cut-off of the amplifiers, the frequency characteristic was designed to fade away gradually after 2·5 Mc./sec., and at 3·5 Mc./sec. is actually approximately 2 db. down. This frequency range introduces many problems into the design of the amplifiers; making it essential that the capacitances of components situated at vulnerable positions in the circuits be kept to a minimum.

In the design of amplifiers handling frequencies in the audible range only, the impedances of the H.T. and other supply circuits can usually be neglected at all but the lower audible frequencies; the latter being largely determined by economic considerations. It will be appreciated, however, that in the present case, at the other extreme, it is essential to transmit very low and zero frequencies, so that the properties of smoothing circuits of the rectifiers, from which the amplifiers are supplied, will in general contribute towards the overall frequency-response of the amplifiers. In consequence, it is a further requirement of design that the impedance of the smoothing circuits should be effectively constant over the range of modulation frequencies.

The requirements that the capacitance should be kept low in order to enable the apparatus to transmit the higher frequencies, and that smoothing circuits should be built out to constant impedance (Appendix 3), introduce difficulties into the design of the amplifiers, especially as constant-impedance networks assume considerably larger dimensions than the more usual form of smoothing circuit.

A supply of higher frequency than the 50-cycle mains largely provides a solution to these problems, because smaller values of inductance and capacitance are required in the smoothing circuits for the same effective smoothing, and the higher supply frequency allows smaller transformers, having reduced capacitances between windings, to be designed. In view of these considerations it was decided to incorporate a 50/500 frequency-changer set having a capacity of 50 kVA. It consists of four machines directly coupled in line, running at 750 r.p.m., and comprises a synchronous motor, inductor-type single-phase alternator, motor exciter, and alternator exciter.

(13) LAYOUT AND DESIGN

The circuits of the modulation amplifiers are shown in schematic form in Fig. 11, which also shows the points at which monitoring facilities are available. The equipment is composed of four amplifiers connected in cascade, which are capable of handling signals of progressively increasing amplitude; their circuits being essentially similar. Each consists of an amplifier stage followed by a cathode-follower, which provides a sufficiently low impedance to withstand the total effective input capacity of the succeeding amplifier. This capacity includes that of a "hold-off" voltage source, of which the potential is chosen to break down the voltage at the cathode of the follower stage to a value suitable for biasing the next amplifying valve. The operating conditions of amplifier and follower stages are chosen in such a way that the anode feeds are approximately in balance, so that the load upon the H.T. supply is nearly constant.* The remnant of unbalanced modulation-frequency current circulating in the H.T. rectifier smoothing circuits makes it necessary to build these out to an impedance which is constant at all frequencies.

Line Amplifier

The first of these amplifiers, the line amplifier, accepts positive signals from the control equipment at approximately 10 volts (double-amplitude peak) with a constant black-level potential of 10 volts. The signals are applied to the grids of the amplifier valve through a variable potentiometer K_1, of which the lower end is returned to

* See Reference (10).

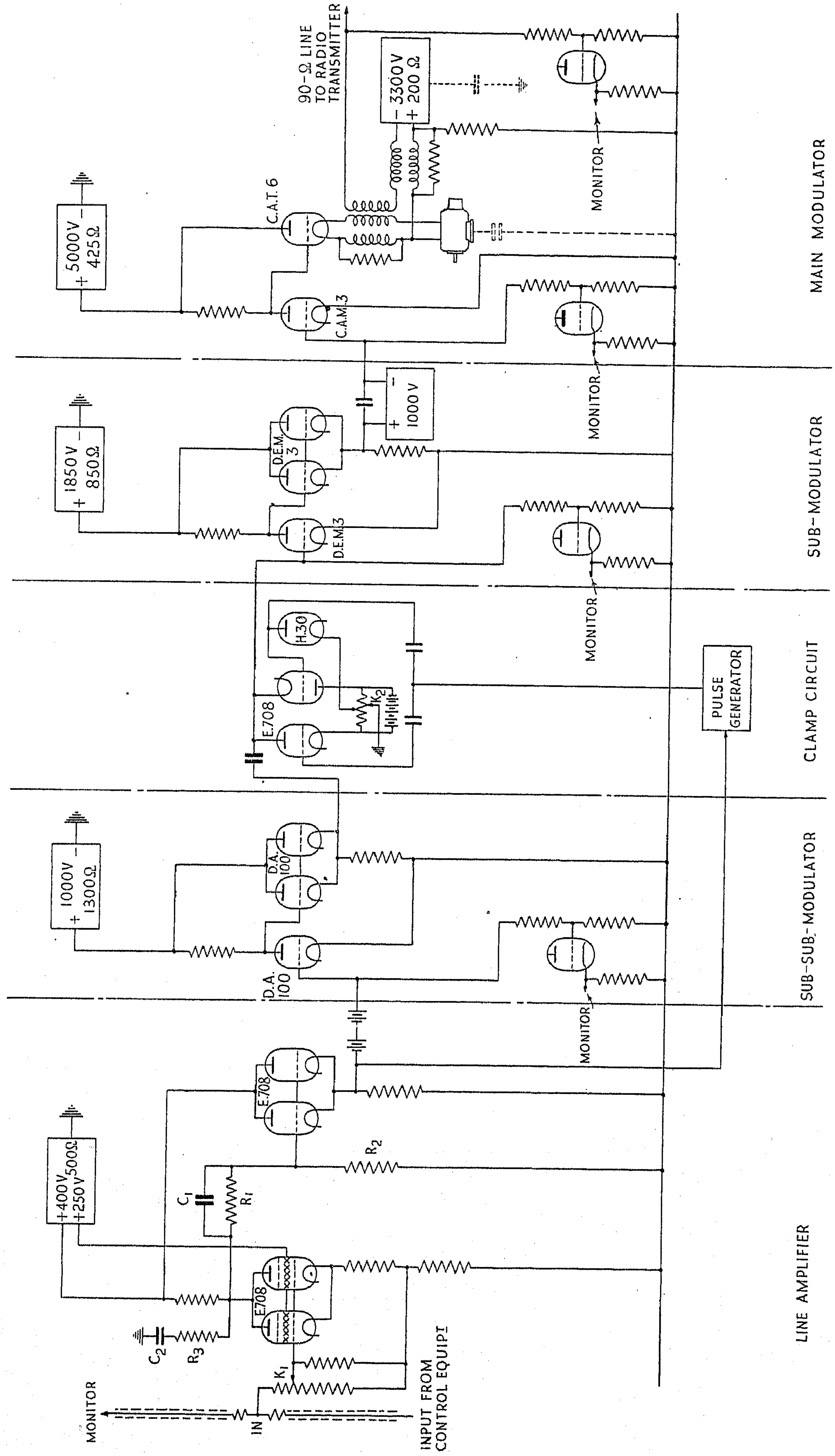


Fig. 11.—Schematic diagram of modulation amplifiers.

a point in the cathode resistance at which the steady potential is + 10 volts. This arrangement enables the amplitude control to be worked without upsetting the black-level potential at the grids of the valves.

The amplifier valves are direct-coupled to the grids of the follower stage via a potentiometer consisting of resistances R_1 and R_2, which ensure that the correct operating conditions obtain for the follower valves. In order to prevent attenuation of the higher frequencies due to the grid capacitance of the follower valves, the resistance R_1 is shunted by a condenser C_1, and the step in the frequency characteristic, introduced when the impedance of C_1 ceases to be small compared with R_1, is compensated by the circuit C_2R_3.*

A battery is included in the direct coupling between the line and sub-sub-modulation amplifiers, of which the voltage is chosen to establish the correct working conditions for the D.A.100 amplifier stage. The capacitance of the battery to earth presents an impedance which is variable with frequency in shunt with the cathode load, and its capacitance is therefore arranged to form part of a constant-impedance network (Appendix 2).

Sub-Sub-Modulation Amplifier

The circuit of the sub-sub-modulator is somewhat simpler in detail than that of the line amplifier, because operating conditions of the two stages are possible such that a direct connection can be made between amplifier and follower valves without resorting to a potentiometer coupling circuit. H.T. supply is provided by a double-wave rectifier circuit employing four U.6 valves, fed by the 500-cycle generator.

Black-Level Stabilization

In the specification of the radiated television-signal wave-form, the amplitude of black level is 30 % of the peak output which represents white in the picture. In view of the small tolerance of ± 3 % allowable for black-level variations, it is necessary to dispense with a direct coupling between the sub-sub-modulating amplifier and the sub-modulation amplifier, and to insert a coupling which holds the potential of the input grid corresponding to black level to a definite value.

A black-level region, free from picture signals and lasting for a minimum of 5 microsec. following the synchronizing signals, is included in the wave-form specification, and auxiliary positive pulses (derived from the synchronizing signals) are used to switch on the two E.708 valves which charge or discharge the coupling condenser between the two amplifiers, so that a fixed potential is established at the grid of the sub-modulator during these 5-microsec. periods.† The black level is therefore "clamped" at regular intervals of approximately 100 microsec. (1 line-period), and as the "clamp" circuit is conductive in both directions no leak is necessary for the coupling condenser. The precise potential to which the grid is switched is made adjustable with a potentiometer K_2 (Fig. 11) on the station control desk, and is used to set the black-level amplitude of the radiated signal.

* See Reference (11).

† *Ibid.*, (12).

Sub-Modulation Amplifier

A D.E.M.3 valve is used in the amplifier stage of the sub-modulation amplifier, which works into two D.E.M.3's in parallel in the cathode-follower stage. The H.T. supply is derived from a double-wave rectifier circuit using two M.R.7A valves; the power being obtained from the 500-cycle supply.

Variations in the values of the anode and cathode resistances would not only disturb the frequency characteristic of the system but would also upset the steady operating conditions of the succeeding stages. Furthermore, the capacitance to earth of these resistances is of considerable importance. After consideration had been given to the various forms which these resistances could take, a non-inductive wire-wound construction was adopted. The resistances themselves are mounted in a duct made from insulating materials, through which a current of air at low pressure is passed.

The coupling between the sub-modulator and the main modulation amplifier contains a rectifier circuit, which develops sufficient potential to "hold off" the voltage of the D.E.M.3 cathodes from the grid of the succeeding amplifier valve. Precautions are necessary to ensure that the capacitance to earth of this hold-off rectifier is kept as low as possible; the 500-cycle supply allowing a transformer to be designed with large clearances between primary and secondary, yet retaining reasonable overall dimensions. Even so, it was found necessary to build out this capacitance to a constant-resistance circuit, as described in Appendix 2. The television signals are negative at this point, and the hold-off rectifier is shunted by a large condenser which acts as a reservoir, so that no appreciable change of grid potential occurs due to the flow of grid current in the succeeding valve during the transmission of synchronizing signals.

Main Modulator Stage

The general arrangement of the main modulator stage is shown in Fig. 12. This indicates the layout of components but does not include the hold-off supply rectifier, which is situated in an adjacent cubicle.

A C.A.M.3 valve (1) is used in the amplifier stage and is directly coupled to a C.A.T.6 valve (2) used in the cathode-follower circuit. Complications are introduced in the output circuit, however, by the provision for filament heating, and by the large dimensions (and therefore large capacitance to earth) of the hold-off supply.

The cathode output circuit of the modulation amplifier is connected to the grids of the output stage of the radio transmitter through the hold-off voltage supply, and as considerable grid current flows during peak picture-signals the effective impedance of this supply must be made sufficiently low. In addition to the rectifier circuit, therefore, a cathode-follower stabilizing circuit is included, and the control voltage for it is derived from an auxiliary rectifier. By taking advantage of the 500-cycle supply the capacitance to earth of the hold-off unit was kept down to 400 $\mu\mu$F including transformer capacitances, and has subsequently been trimmed to 532 $\mu\mu$F to suit the series inductance.

The hold-off unit also contains the C.A.T.6 cathode resistance, and the capacitance of the unit is built out

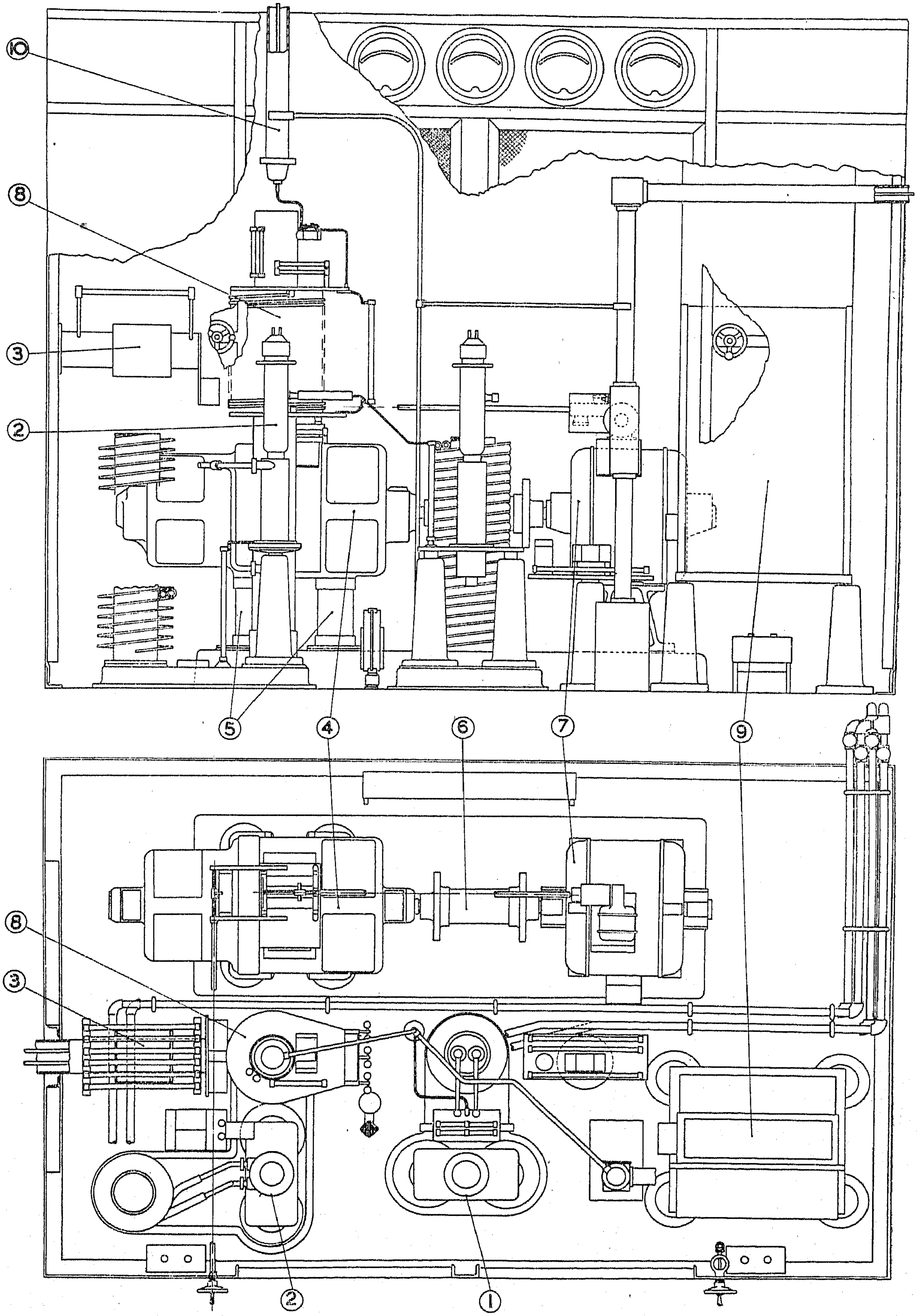


Fig. 12.—General arrangement of main modulator.

with a double-wound inductance (3) to appear as a constant impedance between earth and the filament-heating generator for the C.A.T.6 valve. This generator (4) is situated in the main-modulator cubicle, and is isolated from earth by supporting pillars of insulating material (5) and an insulated coupling (6) to the motor (7). Its capacitance to earth is 75 $\mu\mu$F, and is incorporated in a constant-impedance network which includes a triple-wound inductance (8) and the constant impedance presented by the hold-off circuit. The main features of this output circuit are indicated in Fig. 11, and further details are contained in Appendix 2.

Two of the windings of the inductance for the generator constant-impedance network consist of helices of copper rod of sufficient copper section to carry the filament current. In preference to making adjustments to the value of this inductance during calibration, it was intentionally made slightly larger than the value required by calculation, and a small variable trimming condenser was incorporated to pad up the capacitance of the filament generator to earth.

The same requirements obtain for the anode (9) and cathode resistances for the main modulator as for those in the sub-modulation amplifier, except, of course, that those associated with the C.A.M.3 and C.A.T.6 valves should be capable of dissipating more power. These resistances consist of asbestos woven mats enclosed in air ducts fabricated from insulating material, through which a current of air passes at low pressure. They will handle the 4-kW peak in the anode resistance or the 12-kW peak in the cathode resistance, with negligible change in the value of the resistance.

A mercury-pool rectifier is employed in a double-wave rectifier circuit for the H.T. supply for the main modulation amplifiers. The rectifier itself is of the glass-bulb variety, containing two anodes and a common cathode, the arc being struck by means of magnetically-operated auxiliary electrodes. Mercury-pool rectifiers possess a particular advantage when used in conjunction with constant-impedance smoothing networks, in that the resistance in the conducting state is very low.

The output of the modulation amplifiers is connected to the grids of the output stage of the radio transmitter through a concentric feeder (Item 10, Fig. 12) which is designed to withstand the 2 000 volts of modulation signals.

Monitoring Facilities

In order to maintain a check upon the operation of the amplifiers, potentiometers are included at selected points, by means of which signals at 10 volts amplitude are transmitted by local cathode-followers to the control desk through 150-ohm feeders. A direct-coupled amplifier is incorporated in the control desk, so that accurate comparisons may be made on a cathode-ray tube of the signal shapes, including d.c. level, at the monitoring points. In addition to the points shown in Fig. 11, a diode rectifier and a cathode-follower valve are attached to the feeder to the aerial, to provide a check upon the transmitted wave-form.

500-Cycle Alternator Load Distribution

In order to reduce the interaction between the various loads supplied by the alternator due to its regulation, the distribution network shown in Fig. 13 is used.* The regulation is mainly inductive and is composed of the inductive reactance of the armature and the armature reaction; the latter is made small by working the machine with a field which is nearly saturated. Tapped chokes are included in the load-distributing circuits, of which the first splits the load of the mercury-pool rectifier from the remainder of the loads. The mutual inductance between the two windings is equal to the equivalent inductance of the alternator, so that the voltage-drop across the alternator, due to the load of the mercury pool, will be effectively replaced for the complementary load. This process of load-splitting is repeated for each load on the

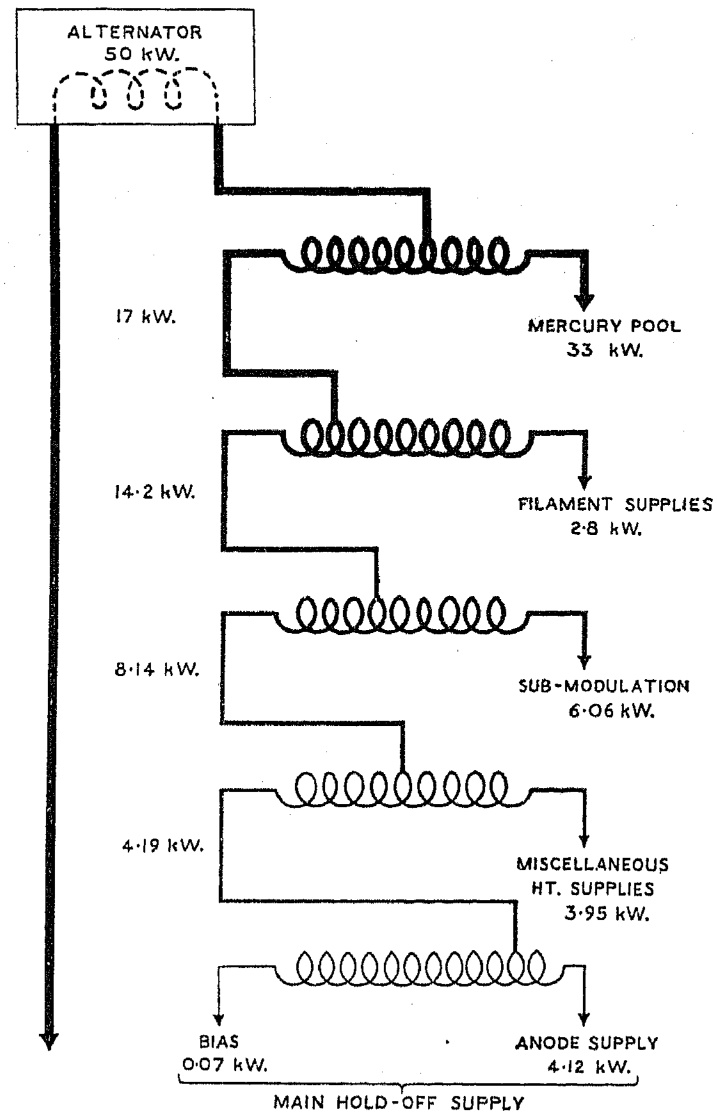


Fig. 13

machine; the mutual inductance being adjusted to equal the total inductance preceding the coil in question. With this arrangement there is virtually no transmission path from one load to another. At normal full load, however, the chokes are not magnetized, so that there is no general increase of regulation or loss of kVA.

Control and Interlock

The 500-cycle frequency-changer set and pumps for water cooling are hand-started, after which the modulation amplifiers can be operated from the control desk. A series of push buttons are provided of which the sequence of operation is determined by an automatic motor-driven selector. The push buttons themselves are

* See Reference (13).

interlocked to one another, so that switching-on of the various units can only be performed in the correct order. Failure of any part of the circuit operating an interlock will automatically prevent further damage to other parts of the system. Raise-lower controls are provided for the 500-cycle voltage-adjustment and filament motor-generator sets; remote meters fitted to the control desk facilitate the adjustment to valve feeds, filament voltages, etc.

Safety Precautions

The amplifier cubicles are arranged in line as shown in Fig. 14 (Plate 2), and a shaft running the length of the cubicles interlocks the gates with a main-supply trip and earthing switches. The shaft is operated by means of a handle at one end, and is arranged so that dangerous voltages cannot be applied until the gates are shut. Conversely, the gates cannot be opened until the dangerous voltages have been switched off and the high-voltage conductors have been earthed.

(14) CALIBRATION AND PERFORMANCE

Calibration and adjustment of the amplifiers involved three processes. The first requirement was the measurement of the component circuits which form portions of each amplifier stage, and the adjustment of the constant-impedance networks, of which there are a considerable number. A discrepancy in the results obtained from any one of these subsidiary circuits might well have given rise to endless searching for a variation of the overall frequency characteristic from that expected from calculation. In the second process the amplifiers themselves were adjusted and a frequency calibration was made. The final process involved measurement of an overall frequency-characteristic (Fig. 15) of the amplifiers; any divergence of the final calibration from that expected from the sum of the characteristics of the constituent units indicated the presence of feed-back. In the latter connection, considerable care had to be paid to the design of connecting wires and earth-return circuits, for a connecting wire only a few feet long may present appreciable reactance within the range of modulation frequencies. Included also in the final tests was the comparison of rectangular pulses as transmitted by the amplifiers with those applied to the input terminals; a test which immediately provided a very fair indication of the performance of the equipment.

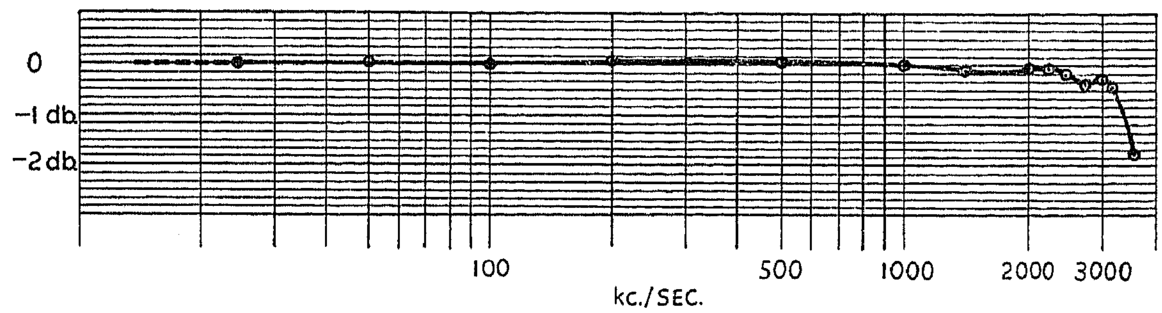


Fig. 15.—Overall frequency characteristic of modulation amplifiers.

(15) ACKNOWLEDGMENTS

The construction of the Alexandra Palace equipment involved the united efforts of a number of engineers. Acknowledgments are due to Mr. I. Shoenberg, Director of Research to Electric and Musical Industries, Ltd., and to Mr. G. E. Condliffe and the staff of the Research Department, among whom Mr. A. D. Blumlein, Mr. E. L. C. White, Mr. E. A. Nind, Mr. J. Hardwick, and Mr. F. Blythen should be mentioned.

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The following is a list of relevant British Patents to which reference may be made for more complete information.

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(2) C. O. Browne, J. Hardwick, F. Blythen, and E. L. C. White: No. 450675.
(3) E. L. C. White: No. 471731.
(4) C. O. Browne and J. Hardwick: No. 419441.
(5) C. O. Browne, E. C. Cork, and M. B. Manifold: No. 448097; A. D. Blumlein, No. 455858.
(6) M. B. Manifold: No. 443952.
(7) M. B. Manifold and A. D. Blumlein: No. 471103.
(8) E. L. C. White: No. 462110.
(9) A. D. Blumlein and E. L. C. White: No. 474607.
(10) E. L. C. White: No. 462536.
(11) E. L. C. White: No. 456450.
(12) C. O. Browne, F. Blythen, and A. D. Blumlein: No. 449242.
(13) A. D. Blumlein: No. 461004.
(14) A. D. Blumlein: No. 448421.
(15) A. D. Blumlein: No. 462530.
(16) A. D. Blumlein: No. 421546.

APPENDIX 1

The Cathode-Follower

General.

The impedance of a triode between cathode and earth, with grid and anode effectively earthed, is

$$\frac{R_a}{m+1} = \frac{m}{m+1} \cdot \frac{R_a}{m} = \frac{m}{m+1} \cdot \frac{1}{g}$$

where m is the amplification factor, R_a is the resistance, and g is the mutual conductance. The open-circuit voltage developed between cathode and earth when E volts are applied to the grid will be

$$\frac{m}{m+1} \cdot E$$

If m is large the open-circuit impedance is therefore approximately equal to the reciprocal of the slope of the valve; and the open-circuit voltage is approximately

equal to the input voltage impressed upon the grid. With a cathode resistance large compared with $1/g$, the cathode potential will follow the grid potential both in amplitude and in phase: hence the name "cathode follower" which is given to the circuit. The negative feed-back introduced by the load in the cathode circuit increases the linearity of the valve; the voltage-swing it is capable of handling being limited by the voltage of the H.T. supply.

Cathode-follower circuits are frequently employed in the television equipment, and a number of typical examples of their use are given below.

Case 1. High input impedance: Emitron-camera input circuit.*

The first valve in the head amplifier is a high-slope triode connected as a cathode-follower with large cathode resistance, and it constitutes a low-impedance source for feeding the succeeding amplifier stage. By virtue of the fact that the cathode potential follows the grid potential, the grid-to-cathode capacitance is effectively removed. The capacitance to earth of the signal plate of the Emitron (which is connected to the grid of the first valve) is also reduced by surrounding it with a shield connected to the cathode. The Emitron is worked with a high load-resistance, and compensation is subsequently introduced for the loss of the higher frequencies. A higher input resistance is made possible by the use of a cathode-follower, and the overall result from this arrangement is a better signal/noise ratio than would be realized by a lower input resistance and a conventional amplifier circuit.

Case 2. Low output impedance.

Cables for interconnecting the various units used in the equipment usually take the form of small feeders, and in order that these shall be of a good practicable construction so that they may be handled without fear of breakage the inner conductor consists of a wire of comparatively heavy gauge. In consequence, the characteristic impedance is low, and it is obvious that difficulties will be encountered in feeding lines of this type from the anode circuit of a valve if a direct coupling is used. The practice has therefore been adopted in this equipment of including a cathode-follower in the output circuit of each unit, so that the disadvantage of a high steady potential superimposed upon the output signals is eliminated. This arrangement has the advantage of simplicity, and the circuit is, in general less susceptible to anode-supply impedance and voltage fluctuations.

Case 3. Cathode-follower feeding a capacitive load.

An example of this condition arises in the case of the C.A.T.6 cathode-follower stage of the modulation amplifiers; this stage feeds the television signals into the input capacitance of the radio transmitter and connecting line.

In general, variations of potential at the cathode would lag behind the corresponding variations on the grid by an amount determined by the cathode-circuit time-constant. In the conducting state, the time-constant of the cathode circuit of the valve will be $C \,.\, R/(1 + Rg)$, where C is the capacitance of the load in shunt with the cathode load-resistance R and cathode impedance $1/g$.

* See Reference (14).

If, however, a rapid negative pulse of large amplitude is applied to the grid, so that the rate of change of grid potential is appreciably greater than that of cathode potential, the grid may depreciate in potential with respect to the cathode far enough to cut off the anode current. Momentarily, therefore, a longer time-constant, determined by the product of C and R, is operative until the valve again conducts, after which the rapid time-constant will be realized for the completion of the pulse.

In the design of a stage in which this possibility exists, since the rate of discharge of the capacitance is proportional to the voltage across it, it is desirable to make the initial cathode potential as high as possible, by operating the valve with high anode current. In the particular case of the C.A.T.6 cathode-follower, the picture signals are positive, so that it is improbable that the valve would cease to conduct during the reproduction of wave-fronts which are likely to occur in the amplitude range occupied by the picture signals.

Case 4. Cathode-follower as a voltage stabilizer of low regulation impedance.

In order to prevent instability or cross-talk in the equipment, due to interaction between the various units through the H.T. supply circuits, it is necessary to provide a number of effectively independent supply sources of low internal regulation. For this purpose, stabilizing circuits are provided consisting of cathode-follower valves, in the cathode circuits of which the loads it is required to feed are connected. The grids of these valves are held positive with respect to earth by a bias battery.

The open-circuit voltage available at the cathode of the stabilizing valve will be equal to that of the grid-bias battery V_b plus the voltage V_g necessary to reduce the anode current to zero.

Current may be taken by the load from this source, which has, therefore, a regulation impedance approximately equal to $1/g$; a limit (imposed by grid current) to the amount of current available being reached when the open-circuit cathode voltage has been depreciated by V_g to the voltage of the bias battery only.

A variation of supply voltage applied to the anode of the stabilizing valve will be reproduced at the cathode diminished in the ratio $1/(m + 1)$, so that the voltage as applied to the load is effectively stabilized, and is independent of load fluctuations of the H.T. supply due to other parts of the equipment.

APPENDIX 2

Constant-Impedance Networks

It is well known that either of the circuits shown in Figs. 16(a) and 16(b) will present a constant impedance equal to R at all frequencies provided that $L/C = R^2$. Advantage is taken of this property in the design of the television equipment in several instances, some of which are given below.

Case 1. Stray capacitance of a "hold-off" supply.*

Referring to Fig. 17(a), the capacitance of the hold-off supply, here indicated as a battery connected between anode circuit and following grid, may introduce serious

* See Reference (15).

loss of the higher frequencies, due to the diminishing impedance of the stray capacitance in shunt with the anode load R with increase of frequency. In Fig. 17(*b*) the anode resistance R shunted by the stray capacitance of the battery (C) is connected in series with an inductance L shunted by a second resistance R. The value of the

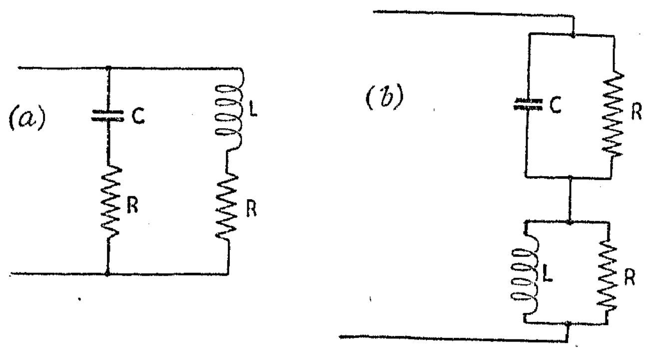

Fig. 16

inductance is determined by $L = CR^2$, so that the anode load now presents a constant impedance R at all frequencies.

The negative battery voltage is applied to the grid through a second winding tightly coupled to the first, the mutual inductance between the two windings being made equal to L. Assuming negligible grid input impedance, any alternating e.m.f. on the anode will be transmitted to the grid, but the impedance facing the grid will be increased by the leakage inductance l of the two coils. By comparison with the circuit of Fig. 16(*a*), if r is the resistance of the battery the impedance of l and r in series can be made constant by connecting a condenser

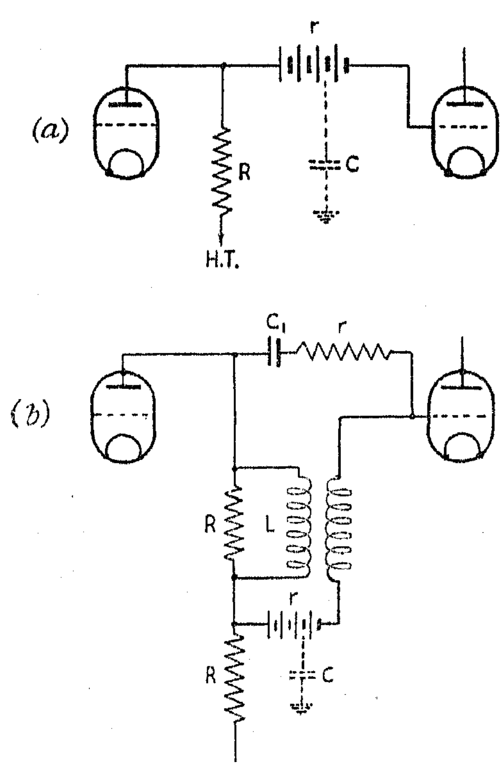

Fig. 17

and resistance in series between anode and grid of the two valves, where the condenser capacitance is given by $C_1 = l/r^2$.

The circuit of Fig. 17(*b*) will now be equivalent to that of Fig. 17(*a*), except that the effect of the stray capacitance of the battery has been completely removed.

Case 2. Filament-heating generator for cathode-follower.

A circuit shown in Fig. 18 is used by which the capacitance of a filament generator may effectively be

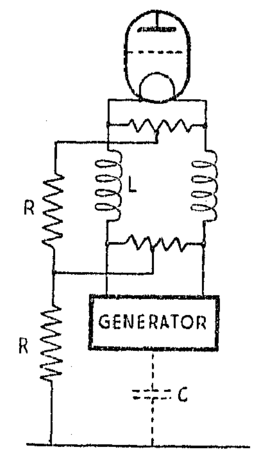

Fig. 18

removed from the cathode of a cathode-follower valve. In this case the inductance consists of a bifilar winding through which the filament-heating current is passed. The coil is shunted by a resistance equal to the cathode load-resistance R, and has inductance determined by $L = CR^2$, where C is the capacitance of the generator to earth.

Case 3. Hold-off supply and filament-heating generator.

In the case in which it is required to include a hold-off voltage supply S_1 in addition to a filament generator S_2, the capacitance to earth of the hold-off supply (C_1) is included in a circuit of constant impedance equal to R, as shown in Fig. 19, where the inductance of the coils is $L_1 = C_1R^2$, and R is given as the cathode load resistance. The effective impedance R of this circuit is shunted to earth by the capacitance C_2 of the filament generator S_2, and the combination is made part of a further constant-

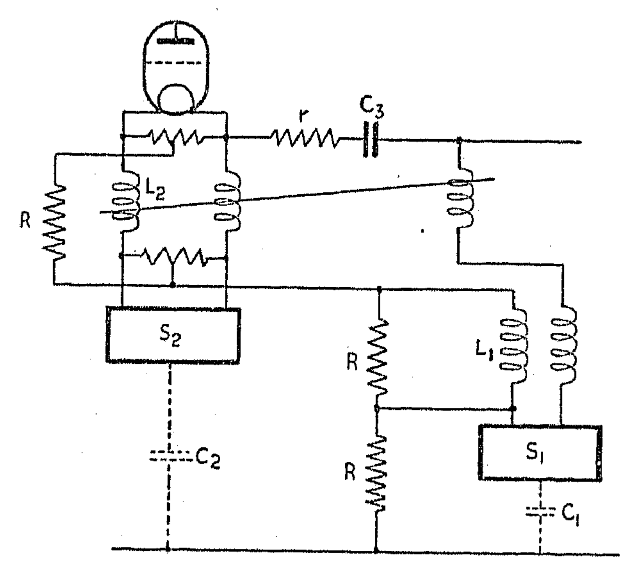

Fig. 19

impedance circuit by the generator inductance L_2 shunted by R. The value of L_2 is given by $L_2 = C_2R_2$.

In order to pass the negative voltage of the hold-off source to the following grid, a third winding is provided which is tightly coupled to L_2. As in Case 1, the leakage inductances l_1 and l_2, which are effectively in series with

the resistance r of the hold-off supply S_1, are corrected by the resistance r and the condenser C_3 in series, where $C_3 = (l_1 + l_2)/r^2$.

In the particular case of the filament generator and hold-off for the main modulation-amplifier stage, the capacitance between the tightly-coupled windings was such as to resonate within the working frequency-range with the leakage inductance. This capacitance, together with the leakage inductance, made an effective transmission line and was treated as such.

Case 4. H.T. smoothing circuits.*

The circuit shown in Fig. 20 is typical of that used for H.T. smoothing in the equipment. Each section of the circuit is made to appear as a constant impedance equal to R, where R is the regulation resistance of the rectifier, by choosing values for the chokes and condensers such that $L = CR^2$. The values of R and L may, of course, be chosen to account for regulation due to the reactance of the supply mains, transformer, etc. The final stage of smoothing has been shown inverted with respect to the preceding stages; an alternative arrangement which still preserves the constant-impedance properties of the network.

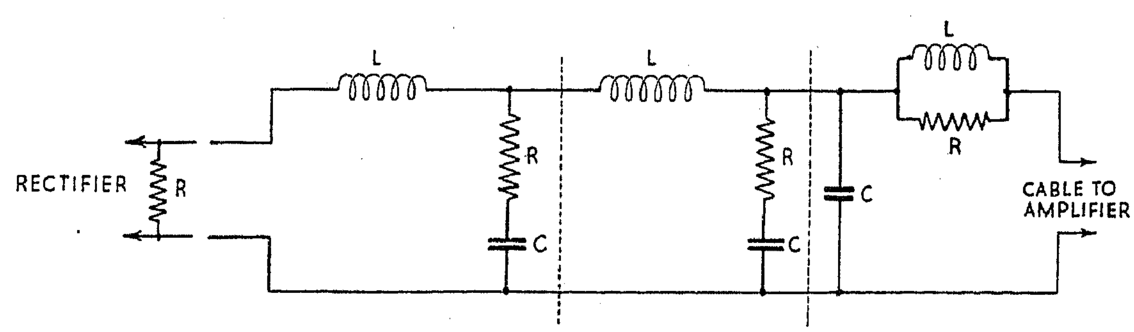

Fig. 20

The cables connecting the H.T. supply circuits to the corresponding amplifiers present considerable capacitance between the positive conductor and earth. This capacitance is shunted at the supply-unit end by the constant impedance of the smoothing circuit, and the cable is made to present a constant impedance to the amplifier by connecting, in series with it, the appropriate inductance and resistance in parallel.

PART III

THE RADIO TRANSMITTER

By N. E. DAVIS and E. GREEN, M.Sc.

(*First received* 3*rd December*, 1937, *and in final form* 10*th March*, 1938.)

SUMMARY

This Part of the paper sets out the agreed specification of the vision transmitter of the London Television Station. Details of the valves available for meeting the requirements are given, and their calculated performance in the balanced bridge circuit of the final modulated amplifier is outlined. This is followed by an examination of:—

(1) The mechanical assembly, with particular reference to the essential features governing the design of the various components.

(2) The control of the amplifier by the television signal, and the conditions relating grid input-volts and output-power to the aerial feeder.

(3) Special requirements of the system.

The Appendix includes a note on the determination of the compensating capacitance for grid-lead reactance, and general data regarding the transmitter.

* See Reference (16).

(1) INTRODUCTION

The Marconi-E.M.I. radio transmitter at Alexandra Palace is the product of continuous research and development initiated early in 1931. At that date the E.M.I. scanning equipment employed a mirror drum producing 120-line pictures, 25 pictures per sec., with sequential scanning, and required a signalling frequency-band of 0 to 180 kc./sec.

The first experimental transmitter, of peak power 400 W on 44 Mc./sec., was installed at Hayes and used for the development of a basic system of modulation for the efficient and accurate transmission of television signals according to the wave-form specification described in Part I of this paper. During 1932, the first high-frequency Class B power amplifier, to operate on the ultra-short-wave band, was built. The peak power was increased to 4 kW, and at the same time the picture frequency-band width was increased to about 400 kc./sec., corresponding to a 180-line picture, 25 pictures per sec.

1933–34 saw the peak power raised to 12 kW and the band width increased to about 1 Mc./sec., the picture definition having been increased to 240 lines, 25 pictures per sec.

In the spring of 1935, the number of lines per picture was increased to 405, and interlaced scanning was adopted. This involved a further increase in the picture frequency-band, which now extended from zero to 2·5 Mc./sec. At this time, designs for a further increase in power of the transmitter were considered.

Eighteen months later, i.e. during August, 1936, the Alexandra Palace transmitter was installed and in operation.

(2) TRANSMITTER SPECIFICATION

This was as follows:—

Output power.

The transmitter shall be capable of giving an output power to the terminals of the high-frequency (h.f.)

feeder of 17 kW when a steady condition is maintained corresponding to the transmission of a full white picture.

Wavelength.

The working frequency shall be 45 Mc./sec., corresponding to a wavelength of 6·67 m.

Modulation.

The frequency and amplitude response of the transmitter shall be such that the conditions required by the contractor's system of high-definition television—employing 405 lines, 25 pictures per sec., interlaced, to give 50 frames per sec., each of 202·5 lines—shall be satisfied.

Summarized, the conditions to be met are: 17 kW peak output at 45 Mc./sec., effectively modulated over a total band width of 5 Mc./sec.

(3) TRANSMITTING VALVES

The specification of the transmitter was based on experimental knowledge and calculated performance of a final grid-modulated power amplifier employing two C.A.T.9 Marconi valves operating in a balanced bridge circuit.

A valve of this type is shown in Fig. 21 (Plate 2), and approximate data for it are as follows:—

Filament volts:	18–20 volts,
Filament current:	100 amperes,
Anode volts:	9 000/15 000 volts,
Emission current at 90 % saturation:	12 amperes,
Maximum anode loss:	18 kW,
Amplification factor:	45,
Impedance:	4 500 ohms,
Length of anode:	12 in.,

Inter-electrode capacitance: grid to anode, 17·6 $\mu\mu$F; anode to filament (earth), 16·0 $\mu\mu$F; grid to filament, 29·2 $\mu\mu$F.

The expected performance of a pair of these valves operating at 45 Mc./sec. in a push-pull circuit capable of effective modulation over a total band-width of 5·0 Mc. may now be examined. The constants of the anode circuit will be chiefly determined by the valve capacitances. Assuming that in the bridge circuit the grid-to-anode balancing condensers are equivalent in capacitance to the valve, the contribution from this source plus the anode-earth (filament) will be 25·6 $\mu\mu$F. To this must be added the capacitance to space of the valve jackets and the members necessary to provide surfaces for balancing and tuning purposes, as well as the minimum capacitance of the variable tuning member. When these are taken into account a minimum figure for the total anode-circuit capacitance will be about 32 $\mu\mu$F. At a frequency of 45 Mc./sec. the capacitive reactance of the anode circuit will be 110 Ω, and the inductance, of equal reactance value, 0·39 μH.

With these values in mind we may now determine the impedance into which the valve must work and the operating conditions which follow from it. As a basis of design it was decided that the Q value of the anode circuit should be such as to give half power response when the circuit was excited by frequencies 2·5 Mc./sec. above or below the carrier frequency.

Let

f = carrier frequency = 45 $\times$ 10^6 cycles per sec.,

$\omega = 2\pi f$,

Δf = frequency-difference between two half-power points = 5 $\times$ 10^6 cycles per sec.,

C = capacitance of anode circuit = 32 $\mu\mu$F,

L = inductance of anode circuit = 0·39 μH,

I = available emission per valve = 12 A,

R = effective series resistance of anode circuit,

R' = effective load on each valve during the active half-cycle,

I_0 = oscillating current in anode circuit,

V = d.c. anode voltage,

v = minimum anode volts,

and $2(V - v)$ = peak h.f. volts across anode circuit.

Then we have

$$\frac{\Delta f}{f} = \frac{1}{Q} = \frac{R}{L\omega} = RC\omega \quad . \quad . \quad . \quad . \quad (1)$$

$$R = \frac{\Delta f}{f} \times \frac{1}{C\omega} = \frac{5}{45} \times 110 = 12{\cdot}2 \text{ ohms}$$

As each valve works into half the circuit for half the time,

$$R' = \left(\frac{L\omega}{2}\right)^2\left(\frac{1}{R}\right) = \left(\frac{1}{2C\omega}\right)^2\left(\frac{fC\omega}{\Delta f}\right) = \frac{f}{4C\omega\Delta f}$$

$$R' = \frac{1}{8\pi C\Delta f} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$R' = 250 \text{ ohms}$$

If the full emission, I, is to be used,

$$V - v = R'I = 250 \times 12 = 3\,000 \text{ volts}$$

$$V - v = \frac{I}{8\pi C\Delta f} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

$$\text{Maximum output} = \frac{(V-v)I}{2} = \frac{I^2}{16\pi C\Delta f} \quad . \quad (4)$$

Fig. 22 shows the anode-current/anode-voltage characteristics of the C.A.T.9 valves, with the load line AB set in a suitable position. The maximum useful anode voltage is limited to 5 500 volts, no matter what the nominal working voltage of the valve may be. The half-ellipse shown is the load line for the extreme side-band frequencies, and lies reasonably within the linear portion of the characteristics.

$$\text{Peak power input} = \frac{2VI}{\pi} = \frac{2 \times 5\,500 \times 12}{\pi} = 42 \text{ kW}$$

$$\text{Peak power output} = \frac{(V-v)I}{2} = \frac{3\,000 \times 12}{2} = 18 \text{ kW}$$

$$\text{Peak efficiency} = \frac{18}{42} = 43\ \%$$

$$\text{D.C. grid bias} = -\ 150 \text{ volts}$$

$$\text{Peak grid-swing} = 1\,500 \text{ volts}$$

These theoretical figures for loading conditions, power

output, and frequency response, agree very closely with those actually obtained.

Equations (3) and (4) are useful for judging the possibilities of a valve for television purposes. They show that the maximum allowable anode-swing and the output

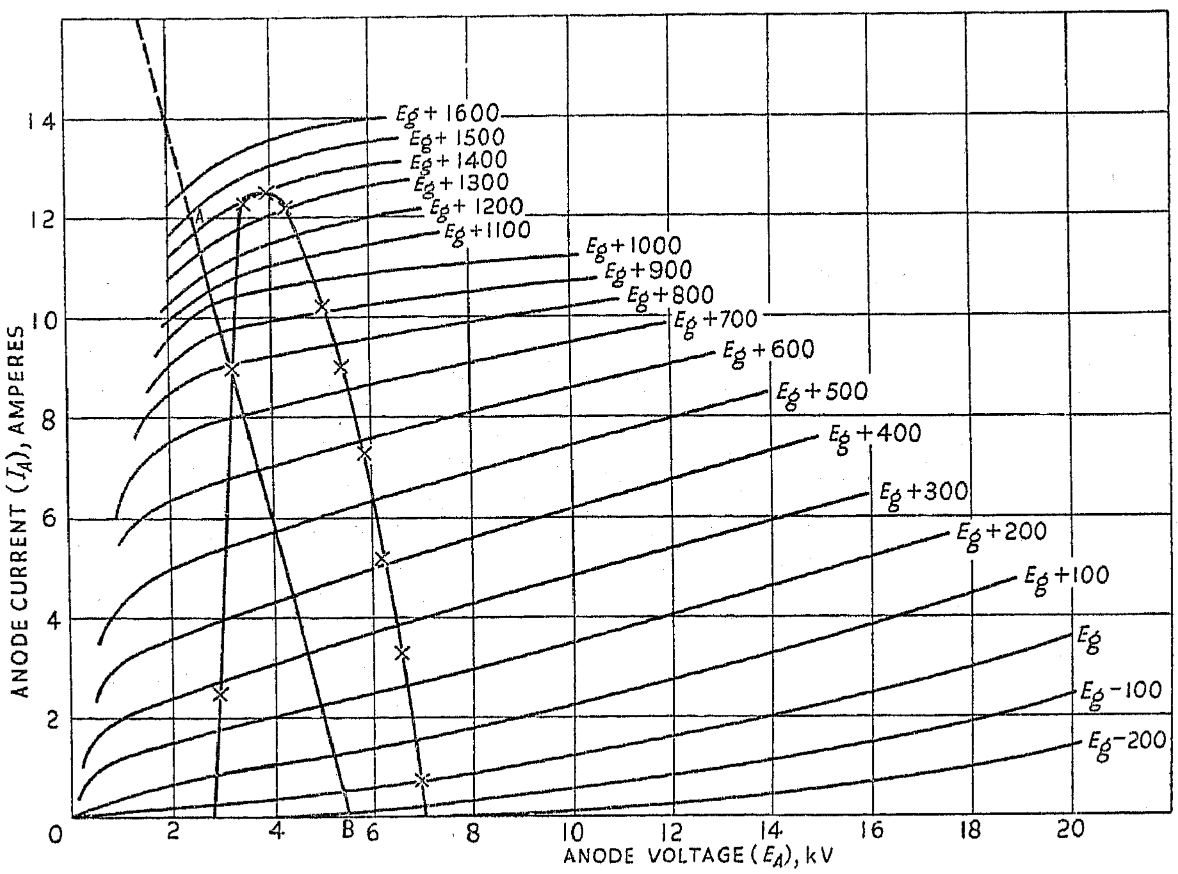

Fig. 22.—C.A.T.9 anode-voltage/anode-current characteristics.

are determined by the peak emission, the circuit capacitance (which is determined by the valve capacitances), and the band width.

For a valve to be suitable for wide-band television the ratio of peak emission to grid-anode capacitance should be as high as possible. Beyond a certain point, however, this capacitance can only be reduced at the expense of transit time. The C.A.T.9 valves are a good compromise in this respect, as although the effects of transit time are apparent in loading of the grid circuit the transit time does not seriously affect the efficiency.

If, however, the required sideband-width were doubled the maximum possible anode-swing and output would be halved, and the efficiency much lower. The carrier frequency is not involved in equations (3) and (4), but only the sideband width. Hence increase of carrier frequency will not give the valves any easier conditions by reducing $\Delta f/f$.

A further point of importance is that the inductance of the connections inside the valve, both for the grid and for the filament, but especially for the grid, should be kept as small as possible. The reason for this will be disclosed when the fundamental circuits are being discussed.

(4) FUNDAMENTAL CIRCUIT

The schematic arrangement of the bridge circuit of the final amplifier is shown in Fig. 23, and the two preceding stages are similar. The arrangement does not differ from that used in the normal commercial short-wave band, except in the care given to mechanical details to maintain symmetry and keep the circuit capacitances and the inductance of high-frequency connections down to the absolute minimum.

The ideal condition to be fulfilled is that the bridge should remain balanced over the whole range of carrier and sidebands, i.e. any voltage across B_1B_2 shall produce no voltage at D_1 and D_2 or at the active grids G_1G_2. The condition as regards D_1D_2 is fulfilled if the resultant inductances and capacitances in the arms are equal, each

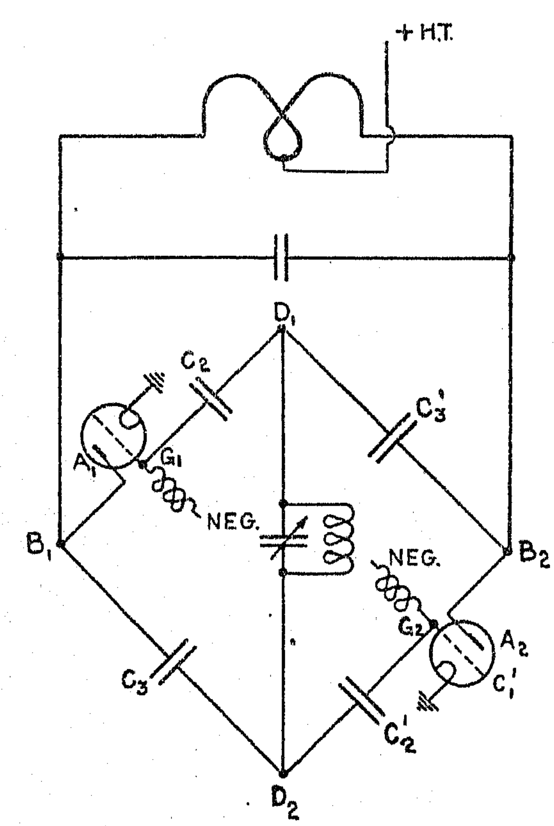

Fig. 23.—The fundamental circuit.

to each. This can be ensured by careful mechanical design.

For no volts at G_1 and G_2 we must have zero reactance between G_1 and D_1 and G_2 and D_2, since a large proportion of the h.f. current in the plate circuit flows across the bridge. This condition is fulfilled at the carrier frequency by inserting the condensers C_2, C_2'. For the sidebands there will be a small residual voltage at G_1 and G_2 which will tend to depress one sideband and augment the other.

For the C.A.T.9 valves the quantitative relations are set out below.

Let C_1 = grid-anode capacitance = $17 \cdot 5\ \mu\mu$F,

l = inductance of grid lead = $0 \cdot 125\ \mu$H,

$\omega = 2\pi \times$ frequency $= 2\pi \times 45 \times 10^6$,

$\delta\omega = 2\pi \times$ change of frequency $= 2\pi \times 2 \cdot 5 \times 10^6$ for extreme sidebands,

$$C_2 = \left.\begin{array}{l}\text{capacitance such that} \\ \quad l\omega - \dfrac{1}{C_2\omega} = 0\end{array}\right\} = 100\ \mu\mu\text{F},$$

V = maximum anode voltage-swing = 3 000 volts,

and v_g = voltage developed at G_1 or G_2 due to V.

Then at the carrier frequency, if the condensers C_2 and C_2' were not present,

$$v_g = VC_1\omega l\omega = VC_1 l\omega^2$$

$$= \frac{C_1}{C_2}V = 530 \text{ volts}$$

This compares with a driving voltage on the grid side of about 1 500 volts. The voltage is in the correct phase to maintain oscillations. After the insertion of C_2, we have

$$v_g = VC_1\omega\left[l\omega - \frac{1}{C_2\omega}\right]$$

$$\frac{dv_g}{d\omega} = 2VC_1\omega l$$

For the extreme sidebands,

$$\delta v_g = 2VC_1\omega l\delta\omega$$

$$= \frac{C_1}{C_2}V\left(2\frac{\delta\omega}{\omega}\right)$$

$$= \frac{530 \times 2 \times 2 \cdot 5}{45} = 56 \text{ volts}$$

This residual voltage is proportional to l, and hence the importance of reducing this to a minimum.

Provided, therefore, that the loading of the anode circuit is established as indicated above, the frequency response of the transmitter should be effective over the desired band-width and the amplifier capable of delivering a peak power of 18 kW. For this requirement to be fulfilled, however, a very important condition arises, namely that the impedance of the aerial system constituting the load should be constant and resistive over the complete modulation band-width.

The aerial and feeder problem is dealt with in a separate paper.

(5) 45-Mc. MODULATED AMPLIFIER: CONSTRUCTIONAL DETAILS, AND FEATURES GOVERNING DESIGN OF COMPONENTS

General

The mechanical-electrical assembly of the ultra-short-wave bridge circuit embodying water-cooled triodes must be considered in relation to the type and constructional arrangement of the valves. The relative disposition of the electrodes will determine whether or not a favourable balance of mechanical arrangement and electrical characteristics may be attained.

From this point of view the " single-ended " valve, in which the grid connection is brought out through the same glass envelope as the filament, has some advantage over the double-ended type, in which the grid connection emerges through a separate glass envelope. With this latter type of valve the electrical circuit tends to spread in dimension a comparable fraction of the operating wavelength and, in addition, it is difficult to arrange an assembly in which the grid-to-anode balancing capacitances are of sufficiently low inductance. Furthermore, the geometric disposition of the grid-filament electrodes and connections within the valves results naturally in a circuit of higher inductance than that normal to the disposition of the same elements and connections in the single-ended type.

As previously indicated, the inter-electrode capacitances of the valves represent the principal electrical constant of the circuit. On the other hand, every additional metal member added possesses distributed capacitance and inductance, and it is desirable that a favourable ratio of the total anode inductance should be available for coupling to the load. The main assembly, providing the balancing capacitance and tuning areas, is therefore preferably arranged in relation to the points of attachment of the main inductance and valve anodes so as to result in an interconnection of negligible impedance.

In the disposition of the grid-to-anode balancing members the preferred location will transfer the inevitable inter-capacitances from the anode to the grid side of the circuit, and at the same time facilitate a symmetrical rigid construction of low inductance in these arms of the bridge.

Finally, in order to avoid losses and unwanted additional anode capacitance, the insulated inlet and outlet positions of the water-cooling system should be embodied in the assembly at a point of zero, or almost zero, h.f. potential.

The ideal assembly from the mechanical and electrical point of view would probably be a self-contained block design arranged to receive the valves, and incorporating enclosed waterways and balancing and main condenser surfaces.

The ultra-short-wave amplifier to be described represents a slight compromise in design, in that the standard valve anode water-cooling jackets have been retained, although practically all the desirable features as outlined above have been realized.

Fig. 24 and Fig. 25 are respectively front and side elevation drawings of the final modulated power amplifier of the London Television Transmitter.

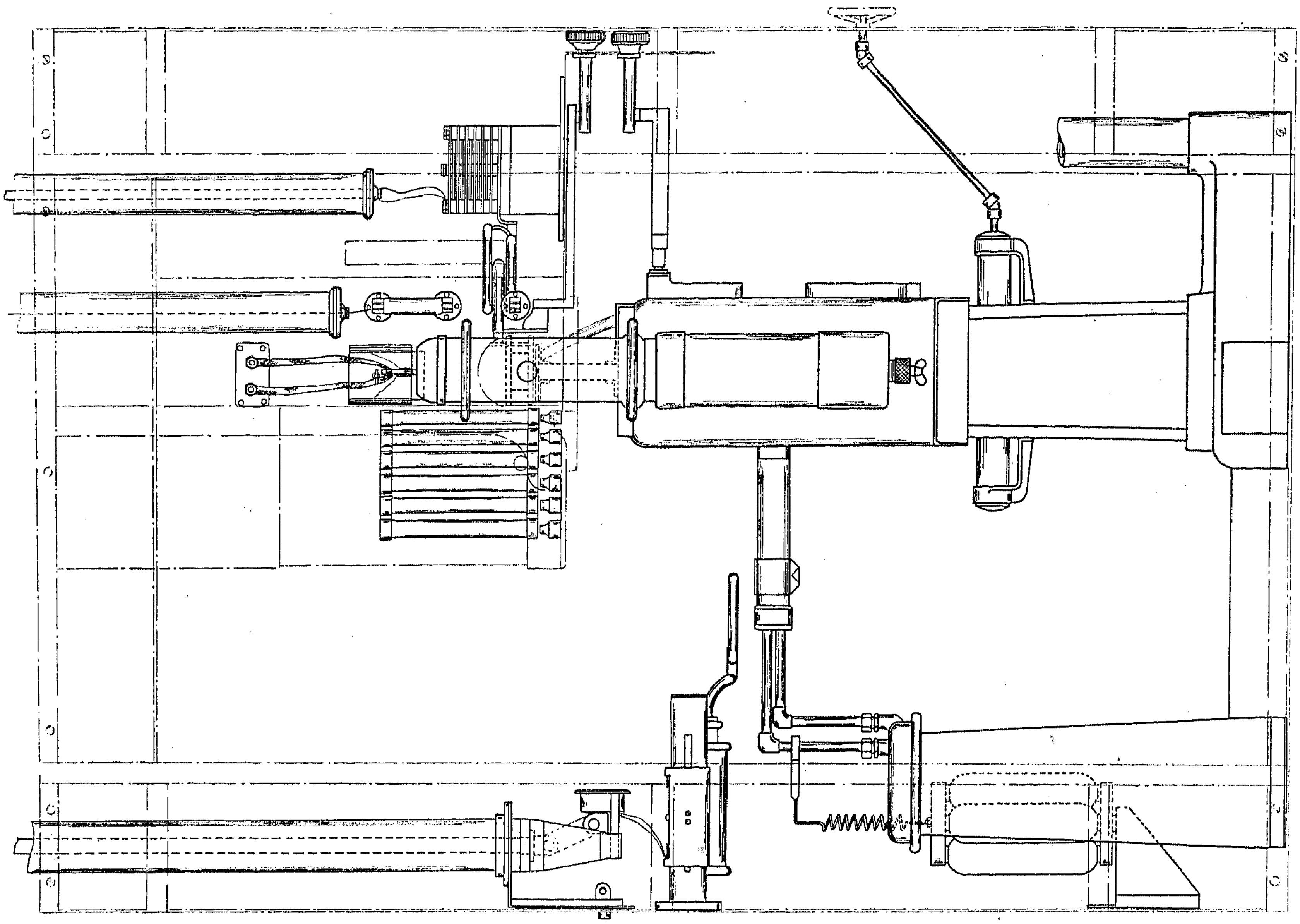

Fig. 25.—Side elevation of modulated power amplifier.

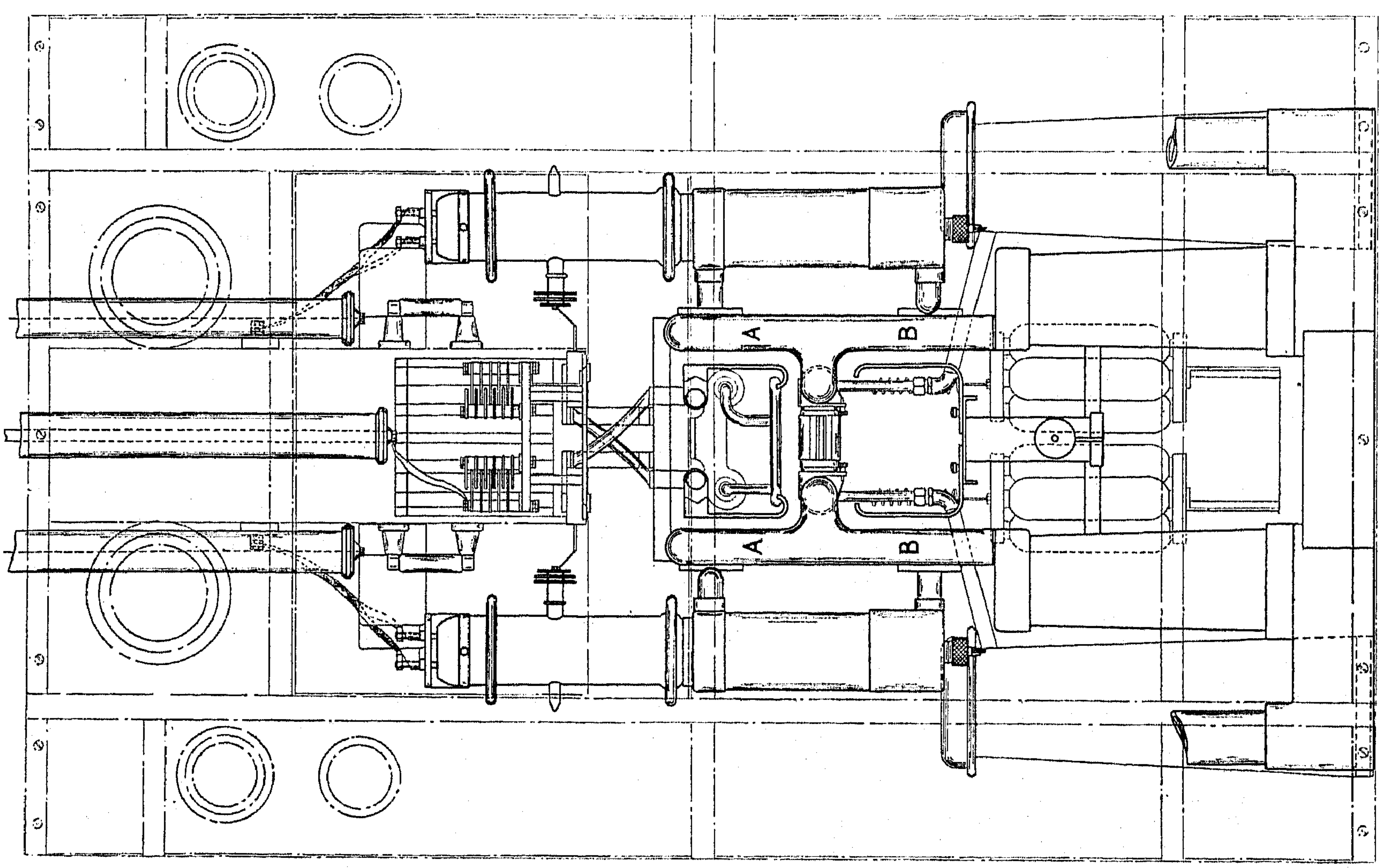

Fig. 24.—Front elevation of modulated power amplifier.

Anode Assembly

Each valve is symmetrically mounted on the vertical outside face of a specially shaped hollow copper member, the other face of which is provided with a short horizontal portion serving to create two independent anode areas A and B. These at the same time provide points of attachment for the external anode inductance, and entrance for the inlet and outlet water connections.

Each member is separately insulated and rigidly fixed to the common base casting by means of mycalex slabs, and the structure is further strengthened by a mycalex cross-tie, which also carries the grid-circuit components.

The anode area A provides the fixed plate of the anode-to-grid balancing capacitance for each valve, while the areas B serve as the fixed portions of the anode-circuit tuning condenser.

The inlet and outlet waterways are formed inside the hollow anode member and terminate in faced surfaces, corresponding with the flanges of the valve jacket, which provide the necessary support, watertight joints, and electrical connection.

Anode Tuning Capacitance

The variable portion of the anode-circuit tuning condenser is a U-shaped structure of depth equal to the anode members, capable of complete withdrawal by means of a travelling nut mechanism cylindrically housed, and controlled from the front panel. The maximum fixed value of the condenser may be altered by lateral adjustment of the plates, and is a valuable feature of the design. It combines the flexibility of adjustment of a comparatively large capacitance with the facility of finally arranging the minimum value convenient for the attainment of maximum impedance of the anode circuit at the operating frequency.

Balancing Capacitances

The variable plates of the grid-to-anode balancing condensers are mounted on integrally-arranged circular guides, the fixed portion of which passes through to the top of the mycalex cross-tie so as to provide ample electrical contact surfaces in the correct position for a natural cross-connection to the grid points of the bridge. The movement of each plate is limited to a partial withdrawal from the anode surface, and is governed by a small travelling nut control, fixed towards the front of the panel, and accessible through metal flaps, which are permanently shut by the front screen during operation of the amplifier.

The inside location of the plates results in a disposition favourable to the attainment of low inductive reactance in the balancing-condenser arms, and also ensures a particularly rigid and symmetrical structure for the attachment of the grid-reactance condensers and grid-circuit tuning inductance.

Grid-Reactance Condensers

Under the conditions of operation of the amplifier, which have already been described, the high-frequency current entering the grid seals will reach a maximum r.m.s. value of 25 to 30 amperes, and the capacitance necessary to neutralize the inductive reactance of the grid-filament structure of the C.A.T.9 type of valve at a frequency of 45 Mc./sec. is of the order of 100 $\mu\mu$F. This defines the limits of design of these condensers, and the full requirement is met by providing an open mica-dielectric assembly, built symmetrically about a substantial single copper plate, so located with respect to the valve grid that a very short interconnection serves to complete the circuit.

The use of these condensers allows the filaments of the valves to be directly earthed without affecting efficiency of operation. Care is taken, however, to limit the inductance of the filament to that contained within the valve structure by providing substantial h.f. bypass condensers to earth at the seals and the point of connection of the d.c. lighting leads.

Grid-Circuit Inductance

The total capacitance presented at the grid points of the bridge is approximately 60 $\mu\mu$F, and the grid-circuit inductance required for a frequency of 45 Mc./sec. is therefore of the order of $0 \cdot 2$ μH. This is obtained by an adjustable trombone, the fixed legs of which are of $\frac{1}{2}$-in. diameter copper tube spaced 2 in. apart. This principle of construction results in a good ratio of loop dimension to inductance, and facilitates magnetic coupling to the exciting amplifier. The loop is cooled by an air stream through the tubes, the point of entry being at the electrical centre so that no electrical unbalance may arise from the necessary attachments. It is of interest to observe that this is a case in which air cooling is justified, as if this is dispensed with by increasing the diameter of the tubes the corresponding decrease in inductance tends to a large and clumsy construction.

The grid coil is coupled magnetically to the output of the exciting amplifier by means of a series-tuned circuit which forms the termination of a 75-ohm concentric feeder. This form of coupling has the advantage of introducing very little extra capacitance.

The series circuit consists of a 2-turn coil, mechanically and electrically centralized with reference to two small variable capacitances of the flat-plate type. The free side of one condenser is connected, by a flexible lead, to the inner, and the other to the outer and earthed conductor of the feeder. The arrangement assists in maintaining the electrical balance of the grid circuit with the use of the unbalanced screened feeder.

The assembly is built up as a self-contained unit, and may be removed completely from the panel, tuned as an independent circuit, and the condensers locked. The condition of symmetry, maintenance of tune, and variability of coupling, is realized by arranging the complete unit to be movable in guides, relative to the fixed coil of the grid circuit.

Grid Damping Resistance

The amplifier is modulated by arranging the television signals to control the negative bias of the grids while these are constantly excited at the operating frequency of 45 Mc./sec. The exact relation between the negative voltage applied by the television signals and the h.f. amplifier output is presented in another section of the paper. It may, however, be noted here that, at vision white, the grids are at the correct voltage for the h.f. amplifier to operate in a truly Class B condition, and that the tips of

the synchronizing pulses correspond to a negative grid voltage somewhat greater than that of the h.f. excitation, and, therefore, zero output.

Under these conditions, maximum linearity of control is realized if the h.f. impedance looking into the grids is constant between the two limits of modulation. In an ultra-short-wave Class B amplifier of the type under discussion this presents a very special difficulty owing to the large proportion of the power, available for grid excitation, which is transferred to the valve anodes and anode circuit. This effect is due mainly to the time of transit of the electrons from the cathode to the anode, within the valve structure, being an appreciable fraction of the h.f. cycle, and which, for the C.A.T.9 valves operating as set out above, appears to be equivalent to about 20 degrees.

With a grid peak excitation of 1'600 volts an anode loss of 2 kW has been measured at zero anode voltage, and during normal operation the loss is probably about 1·5 kW.

In the medium-wave broadcast band it is practicable to keep the impedance of the grid circuits of the h.f. Class B amplifiers appreciably constant during the modulation cycle, and usually only about one-tenth of the available power output of the driving or exciting amplifier is expended in the actual grid circuit; the remaining nine-tenths being absorbed by the damping resistance. It will be realized that to obtain a similar condition in the ultra-short-wave television amplifier would necessitate a driving power considerably in excess of that delivered to the aerial.

At the London Station the maximum power available for excitation of the grids of the modulated amplifier is 6 kW, and this is expended as follows: grid damping resistances, 3 kW; valve anodes, 1·5 kW; grid circuit, 1·5 kW.

The static modulation characteristic of the amplifier, given later, discloses considerable bottom bending, and there is no doubt this could be greatly improved if more power were available. On the other hand, the general linearity is good, and the synchronizing pulses are the only signals affected by the curvature. These are not distorted in shape, but only modified in amplitude, and this may be corrected by increasing the modulation input voltage of this portion of the signal. This is a distinct advantage of the Marconi-E.M.I. form of transmission.

The manner in which the load impedance of the exciting stage is to be stabilized is of some interest. In the 12-kW transmitter at Hayes, mentioned in the Introduction, resistance damping was distributed throughout the circuits. The anode inductance, which is water-cooled, is formed of copper tube sprayed externally with soft iron; the grid-circuit inductance of the modulated amplifier is entirely of soft iron, and air-cooled. This arrangement has the advantage of avoiding additional bulk capacitances around the grids, which is important from the point of view of modulation and general high-frequency symmetry. This system was also adopted for the mobile transmitter, operating at 64 Mc./sec., which has been built for outside broadcasts. By specially shaping the iron in the circuits, and proportioning the power more favourably, the load impedance of the exciting amplifier is made appreciably constant without introducing any additional resistances.

For the London high-power transmitter it was decided to place the whole of the damping in the grid circuit of the modulated amplifier, so as to obtain the best possible linearity of control under the conditions presented. The resistance consists of 16 carbon tubes, connected in series, mounted in rigid symmetry on the grid points of the bridge in a circular air shaft which forms part of the grid-circuit compartment. Each tube is supported on a steatite nozzle connected to a common air-duct—also an integral part of the construction. Air is thus passed through each rod, and a suction fan, mounted at the head of the shaft, quickly removes the hot air from the compartment, and generally assists cooling.

In order to minimize h.f. capacitance effects and equalize the loading, the tubes are graded from a value of 25 ohms at the grid ends to 70 ohms towards the electrical centre and point of zero high-frequency potential. The measured d.c. resistance of the bank is 800 ohms, and at 45 Mc./sec. it is equivalent to a grid shunt resistance of 1 600 ohms.

Anode Circuit

The external anode-circuit inductance is obtained by enveloping the inlet and outlet water-piping by a 2-in. copper tube, which is built as a natural extension to the horizontal portion of the anode members. These two parallel tubes are 11 in. long and spaced 4 in. apart.

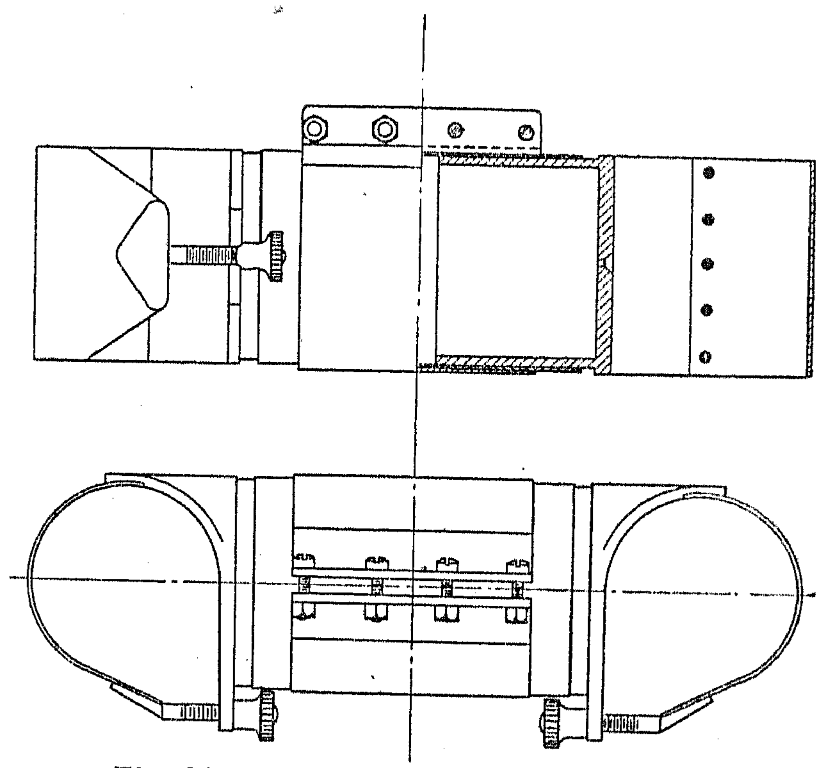

Fig. 26.—Anode-circuit blocking condenser.

The H.T. supply to each valve is connected to the inductance via the water piping, and, as it is desirable that the performance of each valve may be observed, separate anode d.c. feed metering is arranged for by completing the h.f. circuit through a specially designed d.c. blocking condenser mounted between, and capable of adjustment relative to, the inductance tubes.

During the heavily loaded condition of normal operation, the maximum h.f. current in the circuit is about 40 amperes, but this will rise to 90 amperes at no-load. The blocking condenser is therefore designed to carry 100 amperes at 45 Mc./sec. continuously, without undue heating. The construction adopted is shown in Fig. 26.

It is best understood by imagining that the two parallel inductance tubes are formed into an adjustable loop by a $2\frac{1}{4}$-in. diameter copper tube retained in position by phosphor-bronze bands. This interconnecting tube is cut in half, leaving an air-gap of about $\frac{3}{16}$ in., and a sheet of mica placed centrally to the slot envelopes the tube throughout its length. A phosphor-bronze band of slightly less width than the mica sheet is placed symmetrically with respect to it and finally tightened, so that the whole becomes a series tubular mica condenser with the two half-tubes forming the inner plates and the external metal band the common outer plate. Its capacitance as designed is $0{\cdot}002\ \mu$F.

The tubular construction secures an even distribution of the h.f. currents: in addition, the mechanical accuracy with which the main members may be turned, together with the facility afforded for high-pressure location of the metal band over the mica dielectric, removes all possibility of air pockets and ensures a condenser of true characteristics at the ultra-high frequency. This is important, as the inlet and outlet of the cooling water are at this point, and it is desirable that definite control of the h.f. potential should be secured so that water loss in the insulating columns is avoided.

An ordinary multiple flat-plate mica condenser is quite inadequate to fulfil the requirements, besides being less neat and considerably more costly than the condenser designed by the authors. This component is a further illustration of the fact that the ultra-short-wave band requires its own special technique.

Output Coupling Unit

This is a series-tuned circuit designed to operate into 50 ohms. It is so constructed as to be self-contained, both mechanically and electrically, and may be independently tuned either in position or when removed from the panel. The design aims at a high ratio of active to inactive inductance, and also, by minimizing stray capacitances to earth, at complete transfer of the anode-circuit energy to the output feeder. Referring to Fig. 27, it will be seen that the inductance is a flat coil, the free ends of which are developed as the inner members of two separate tubular condensers. The outer tubes are spaced by a mycalex plate, to which they are fixed. Locking guides, mounted on this plate, also carry a mycalex assembly centralizing the inners of each condenser and providing tuning adjustment. The arrangement is completed by a tubular support, which houses a travelling attachment to which one outer tube is fastened; this facilitates external adjustment of the complete unit with reference to the anode-circuit inductance and at the same time constitutes a substantial earth path of low inductance. The outer tube of the second condenser is connected by a flexible strip and h.f. ammeter to a link switch so that the transmitter output may be taken either to the aerial or to test feeders.

Modulation Input

The modulation input, inside the panel, is connected to each grid via an h.f. choke and a separate screened conductor. These conductors are terminated in a junction box (not shown in Fig. 27) mounted externally to the panel, in which a common connection is made to the modulator output, and a monitoring point established.

(6) THE TELEVISION SIGNAL

The wave-form of the television signal as applied to the radio transmitter is illustrated in Fig. 28. The output power of the final h.f. amplifier is plotted from actual test figures as a function of grid negative volts. The vision wave-form, in terms of the negative grid-voltage

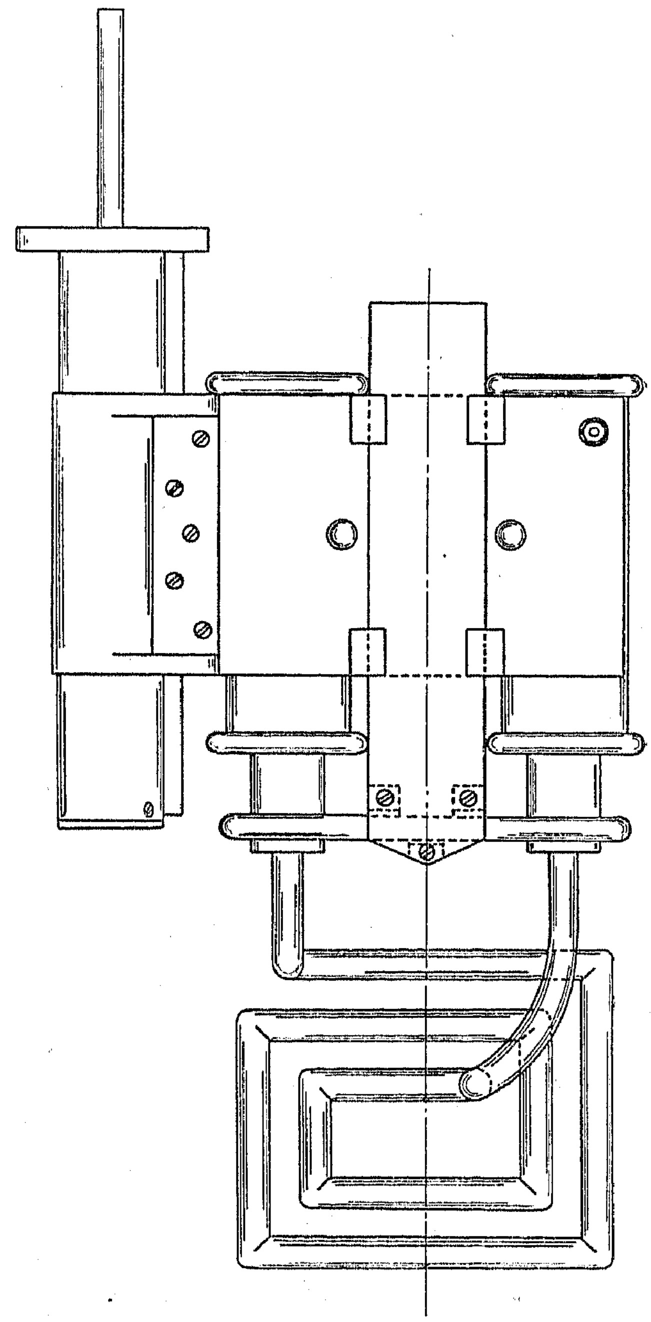

Fig. 27.—Output coupling unit.

scale, is projected on to the curves, and the black-level condition is clearly shown. The vision signals are to the right of the black datum and, for high lights, extend to full output. Intermediate light values attain proportionate outputs from the fixed black level. The synchronizing pulses lie to the left of the black level and are of such amplitude, in terms of grid negative voltage, as completely to shut off the transmitter. It will thus be seen that the h.f. amplifier is fully exploited by the complete voltage-swing of the vision and synchronizing signals, and that the former occupy fully the linear portion of the characteristic.

The peak voltage ratio of these signals, as applied to the grids of the valves, is proportioned so as to result in

an aerial-current output ratio of 10 : 3 between peak white and black level. This corresponds to a radiated signal which, measured from the black datum, defines the limit allotted to the vision and synchronizing signals as having an amplitude ratio of 7 : 3 and constitutes the specified wave-form of the Marconi-E.M.I. system of television.

The input grid peak-voltage ratio shown is 4·5 : 3, but dition obtains, the h.f. amplifier being keyed between a prearranged low level, to represent the black elements of the film, and full output, to represent the white background. The only difference is that, whereas in facsimile transmission independent synchronization allows one of the levels to be zero output, in television transmission the height of the level corresponding to black must be such as to reserve sufficient power to convey effectively

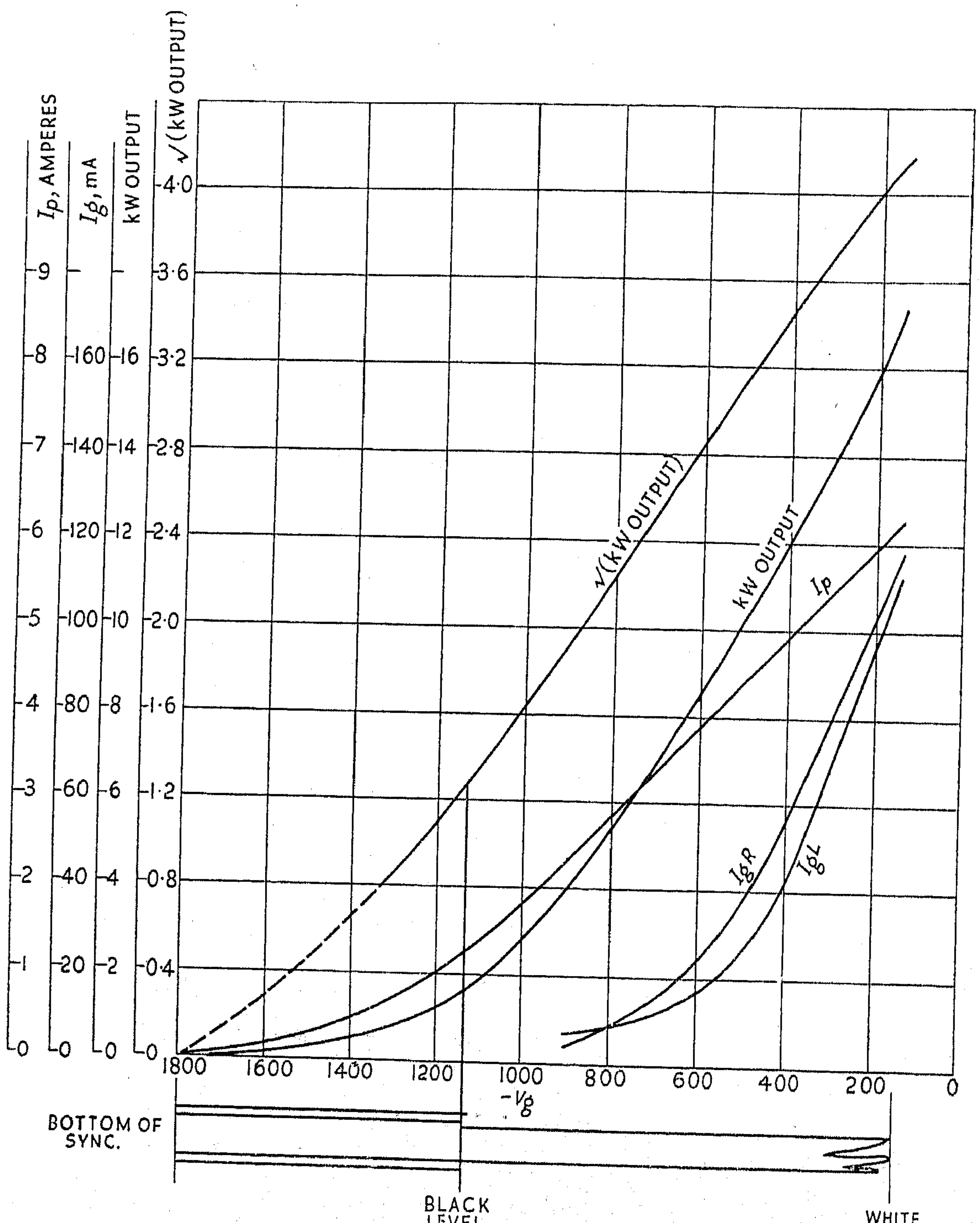

Fig. 28.—C.A.T.9 modulated amplifier. Static characteristic connecting grid negative voltage with output power under constant h.f. excitation.

as the amplitude of the synchronizing pulses is increased beyond zero output so as to ensure the desired rectangular wave-form, the operating ratio is usually very nearly unity.

From the above it will be realized that the Marconi-E.M.I. method of modulation described is akin to that employed in the radio transmission of black-and-white facsimiles. In this case the modulated h.f. amplifier is keyed between two levels of output, one of which represents black and the other white. In the television transmission of a black-and-white film cartoon a similar con- the necessary synchronizing intelligence to the limit of the range of the vision signals. In the television transmission of half tones the h.f. power amplifier is subjected to proportionate keying between the extremes of the black and white levels as defined above.

This form of transmission is known as " d.c. modulation "—in contradistinction to " a.c. modulation," in which the vision signals float about a mean carrier according to the balance of the black to white areas of the elements being transmitted. For a useful detected voltage at the receiver this system results in a great saving of

power at the transmitter when compared with a.c. modulation. The foregoing will clarify the meaning of the term as applied to the radio transmitter.

(7) ANODE-VOLTAGE SUPPLY TO THE MODULATED AMPLIFIER

When the established wave-form of the system is described as possessing a vision white to synchronizing ratio of 7 : 3 in output current, with the synchronizing pulses located at or passing through zero output, it is implied that the black level, about which the ratio is measured, remains fixed under all conditions of modulation.

In the case of the transmitter being described, this level, from the curves of Fig. 26, corresponds to an anode voltage of 5 580 volts and a total anode feed of 1·25 amperes, or an input of 6·9 kW. At vision white the input is very nearly 35 kW, and at peaks of synchronizing pulses it is zero. During modulation, therefore, the h.f. amplifier is keyed from the black level upwards into the high-power area and downwards to zero.

Consideration of the condition will lead to the conclusion that, if the black datum is to be faithfully maintained, the H.T. voltage applied to the anodes of the modulated h.f. amplifier should be kept appreciably constant from zero to full load over a frequency band of preferably 0 to 2·5 Mc./sec., and be free from transients after any type of signal. The requirement extends to zero, or practically zero, frequency owing to the slow variations of general input level, corresponding to mean picture brightness, which occur during transmission. In the case of film these changes to different mean levels frequently occur with abruptness. The requirement is entirely met by using an H.T. anode power source of low and constant impedance over the band of signalling frequencies.

A 3-phase full-wave rectifier of the required power, employing mercury-vapour valves, may be built to an equivalent d.c. resistance of less than 100 Ω if reasonable care is taken in the design of the main transformer and filter chokes. To proportion the circuit so that this value is maintained for a.c. loads and at the same time provide a good level of ripple suppression is costly, and a compromise design is desirable.

Experiment has shown that such a design is practicable, and at the Alexandra Palace and Hayes transmitters a 3-phase full-wave rectifier, fitted with Marconi G.U.3 valves, terminated by a filter circuit in which the ratio $\sqrt{(L/C)}$ is 200, has given satisfactory results.

The electrical capacitance of the H.T. cable from the rectifier to the valve anodes should be prevented from forming a tuned combination with stray or h.f. choke inductance at any frequency within the signalling band, as otherwise the modulation response of the transmitter will be affected. The practice followed at the London Station is to feed each valve through a non-inductive resistance combination of 50 Ω and a quarter-wavelength h.f. choke coil.

This Part of the paper is confined to the theoretical and practical design of the high-power-modulated amplifier of the ultra-short-wave vision transmitter of the London Station, as, in the authors' opinion, wider treatment would obscure the points of major interest. An account of the composition of the complete station, setting out in order the various amplifiers leading up to the final stage, with types of valves and running conditions, is, however, given in Appendix 2.

(8) ACKNOWLEDGMENTS

Finally, the authors desire to express their thanks to Marconi's Wireless Telegraph Co. for permission to publish a description of their work, which is the result of development spread over a considerable period, and to which valuable contributions were made by Mr. F. G. Robb, Mr. W. S. L. Tringham, and Mr. L. Bounds, of the Research and Development Department.

APPENDIX 1

Determination of Compensating Condenser for Grid-Lead Reactance

In the normal process of balancing, the bridge is excited from the grid side, and the balancing condensers are

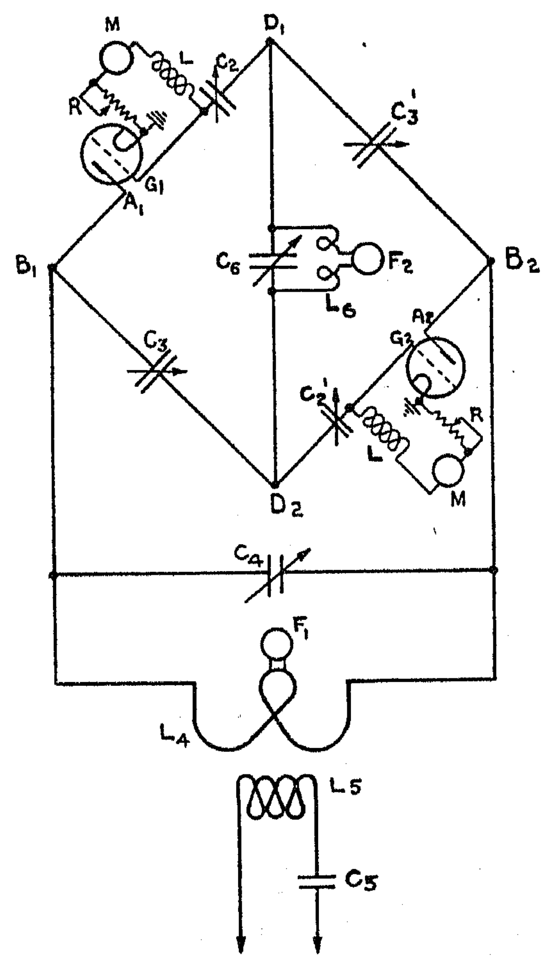

Fig. 29.—Back balance.

adjusted to give zero current in the anode circuit. To determine the required values of the compensating condensers we must be able to measure the voltage between grid and filament produced by current flowing in the anode circuit. This can be done as follows:—

Remove the H.T. and grid-bias supplies, but light the valves. Connect a low-reading milliammeter M and resistance R in each grid circuit, as shown in Fig. 29.

The reading of M will be a measure of the voltage between grid and filament, and the sensitivity can be varied by varying the resistance R. (If an accurate measure of the voltage is required, these arrangements can be replaced by a slide-back voltmeter.) Connect the thermoammeter F_1 in shunt to a portion of the anode inductance L_4, and the thermoammeter F_2 (or shunted lamp) in the grid circuit. Supply high-frequency power from the preceding stage via the main output circuit L_5C_5.

Tune the anode circuit, and adjust the coupling of L_5 to L_4 so as to get a suitable reading on F_1. Then tune the grid circuit for a maximum on F_2. Adjust the balancing condensers C_3, C_3' to make the current in F_2 a minimum. Both anode and grid circuit should be kept in tune during the process, and the current in F_1 maintained at a constant value. Take readings of M. Then the capacitances of the compensating condensers C_2, C_2' are altered and the process is repeated, until the value giving a minimum reading on M is found.

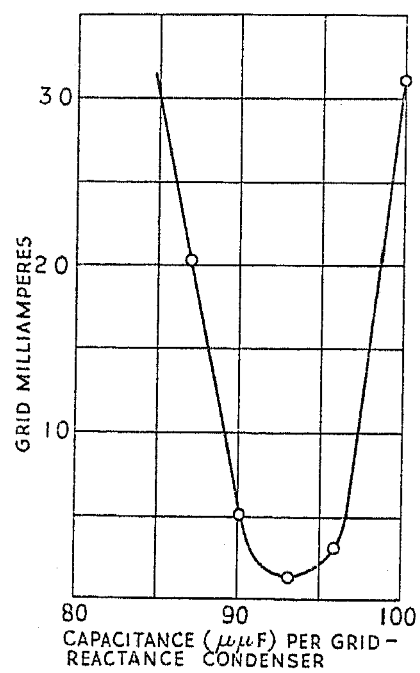

Fig. 30.—C.A.T.9 power amplifier curve of back balance at 46 Mc./sec.

If the bridge points D_1 and D_2 are close together, the process can be shortened. Balance the circuit as previously described. Then join D_1, D_2 by a lead of negligible inductance. Readings of M_1 and M_2 are taken. Then, provided C_2 and C_2' are always kept equal, no further balancing of the bridge should be necessary.

Fig. 30 shows the results obtained with the C.A.T.9 valves at a frequency of 46 Mc./sec., the correct value of C_2 being 94 $\mu\mu$F. The correct value for any other frequency can be deduced from this.

APPENDIX 2

Marconi-E.M.I. Television Radio-Frequency Equipment

The following are the running conditions of the various power amplifiers, with types of valves employed, at the vision transmitter at Alexandra Palace, London, wavelength 6·67 m., frequency 45 Mc./sec.

Power amplifier No.	*Type of valves*	*Running conditions at peak white**	
6th and final	2 C.A.T.9	V_p (volts)	6 000
		I_p, total (amperes) ..	6·45
		I_p, left valve (amperes)	3·26
		I_p, right valve (amperes)	3·19
		I_g, left valve (mA) ..	105
		I_g, right valve (mA) ..	105
		V_g (volts)	−154
		Load amperes	15·7
		kW in	38·7
		kW out	18·6
		Efficiency	48%
5th	2 C.A.T.15	V_p (volts)	5 500
		I_p, total (amperes) ..	1·59
		$(I_g)^L$ (mA)	164
		$(I_g)^R$ (mA)	222
		V_g (volts)	−400
4th	2 A.C.T.9	V_p (volts)	3 600
		I_p (mA)	620
		I_g (mA)	125
		V_g (volts)	−110
3rd	1 A.C.T.9	V_p (volts)	3 200
		I_p (mA)	280
		I_g (mA)	18
		V_g (volts)	−88
2nd	2 A.C.T.6	V_p (volts)	750
		I_p (mA)	138
		I_g (mA)	12
		V_g (volts)	−6
1st	2 M.P.T.42	V_p (volts)	250
		I_p (mA)	70
		I_g (mA)	—
		V_g (volts)	−20
Doubler	1 M.P.T.42	V_p (volts)	250
		I_p (mA)	45
Master oscillator	1 M.P.T.42	V_p	250
		I_p (mA)	37

* V_p = plate (or anode) voltage; I_p = plate (or anode) current; I_g = grid current; V_g = grid voltage.

[The discussion on this paper will be found on page 793.]

DISCUSSION BEFORE THE INSTITUTION, 21ST APRIL, 1938, ON THE PAPERS BY MESSRS. T. C. MACNAMARA AND D. C. BIRKINSHAW (SEE PAGE 729) AND MESSRS. A. D. BLUMLEIN, C. O. BROWNE, N. E. DAVIS, AND E. GREEN (SEE PAGE 758)

Sir Noel Ashbridge: These papers are of special interest because they record a co-operative effort between a commercial firm and a public utility undertaking guided by a Governmental advisory committee. In addition, valuable work has been done by the wireless-receiver industry in designing and manufacturing complex but nevertheless very reliable apparatus for use by the public. The result has been the setting-up of the first public television service in the world. I should like to pay a tribute to the research staff of the Marconi-E.M.I. Television Co., who have achieved so much in the technical development of this difficult subject.

I should like to point out one or two differences on the economic side between sound broadcasting and vision broadcasting, partly because they may explain why several countries abroad are hesitating before launching a public service such as the one in operation in Great Britain. Let us consider first of all the studio equipment, and compare that at, say, Birmingham with that at Alexandra Palace. The studios at these places each produce about the same number of hours of programme per day, but we find that the cost of the studio equipment for vision is no less than 5 times as great as that required for sound. Again, to carry out an outside broadcast of a boxing match, for example, the apparatus for vision costs about 100 times as much as the apparatus for sound broadcasting. Let us now consider the question of staff; first from the point of view of the numbers required and secondly from the point of view of their ability to carry out the work in the two cases. Comparing the studio staff at Manchester with that at Alexandra Palace, we find that the engineers employed at Manchester number 13, while the equivalent figure for Alexandra Palace is 61, and again the hours of entertainment are roughly the same. Secondly, the training of sufficient engineers quickly enough in the complex technique of television is bound to constitute a difficulty for the next few years.

Another difficulty is that the time for rehearsal is inadequate at present. The producer has to accept, after the few rehearsals he can get in, what the performers will produce themselves, as distinct from what he is trying to get them to produce. It is also necessary to conduct a great many rehearsals without any apparatus at all, because it is not available.

One of the surprising facts about the service is the great reliability of the receivers. At the beginning it was far more difficult to synchronize the picture than to synchronize two alternators in a large power-station, but now a television receiver is no more difficult to adjust than a sound receiver. I have just been away from home for rather more than 2 months, and I gave elaborate instructions as to what was to be done should the television receiver fail during my absence. It has, however, worked satisfactorily 4–5 days a week all the time I have been away, without any skilled adjustment or attention.

The performance of the receivers, good as it is, would be very much better if we could get rid of the two forms of interference which are the most troublesome—from electromedical apparatus and from motor-cars. If only some non-technical means could be found for putting into effect the technical findings of Messrs. Gill and Whitehead* the development of television would be greatly helped.

As regards developments in the future, we have to consider the possibility of establishing television stations in the provinces. This raises the question of linking two transmitters together, because it is inconceivable on economic grounds that each transmitter could be provided with a separate programme produced a mile or two away. There are two obvious types of link: one is the special cable and the other a wireless link, consisting of a number of ultra-short-wave transmitters and receivers. I do not know which would be the cheaper or whether one would introduce more distortion than the other, but I realize that it is desirable to keep out of the ether all the transmissions which it is possible to carry in any other way.

Dealing with the question of coverage, the Television Advisory Committee originally estimated a radius of 25 miles, but I thought this very optimistic and suggested that it should be reduced to 15 miles as far as the public was concerned. It has been found, however, that 25 miles is not the limit, the distances obtained varying in different directions. I think too that the limit with regard to the power of transmitters has not yet been reached; this is one of the most hopeful signs in connection with the extension of the television service to other parts of the country.

Another question to which I should like to refer is that of the 405-line standard, which was adopted after careful consideration by the Committee and will remain in use for a period of at least 3 years. This period will give a good deal of scope for improvement of the picture, both at the transmitting end and at the receiving end. Later it may be necessary to adopt a larger number of lines, in order to give a larger picture with increased definition.

Mr. A. J. Gill: I should like to mention, as an instance of the thoroughness with which the development work in connection with the television service was carried out, that Messrs. Electric and Musical Industries installed in their laboratory nearly 8 miles of the balanced cable referred to on page 750 of the paper by Messrs. Macnamara and Birkinshaw, in order to carry out a complete test over the length which it was proposed to use. It was very interesting to see the result of the comparison between the reception direct from the pick-up and the reception through the 8-mile length of cable: it was almost impossible to distinguish any difference between the two sets of pictures obtained. Another very interesting thing which was shown at the same time was the effect of transmitting the picture signal through the cable but sending the synchronizing signals direct from just across the laboratory. The picture took an appreciable time to go through the cable, and arrived about

* *Journal I.E.E.*, 1938, vol. 83, p. 345.

half a line (approximately 0·00005 sec.) late. A calculation of the speed of transmission gives the value of 160 000 miles per sec., which is about what one would expect.

My own interest in this work is largely in connection with the transmission of signals over long distances, for which Messrs. Macnamara and Birkinshaw give three methods—unbalanced coaxial cable, balanced-pair low-capacitance cables, and normal telephone circuits. The first is probably the most economic method of transmission over long distances, but unfortunately the cross-talk sets a limit to the transmission of frequencies below about 100 kilocycles per sec. To avoid this difficulty it would be necessary to move the frequency spectrum up at the transmitting end, by means of terminal equipment something like that used for carrier telephony, and to move the whole spectrum back at the receiving end. To do this would require very complicated apparatus, because of the difficulty of avoiding phase-shift in the equipment; the problem is still being studied, and I think it will be solved in the near future. The balanced cable is, of course, already in use; it is the one which I mentioned seeing demonstrated before it was put in. The work that the B.B.C. is doing on the use of telephone circuits for television purposes is of great interest, because it may offer a solution of the problem of outside broadcasts.

I agree with Mr. Blumlein's remark on page 759 that it is advantageous to transmit pictures with unity γ, and would even suggest the use of a fractional γ. The Post Office on the transatlantic telephone circuit is using a compandor, which produces the equivalent of a fractional γ ($\gamma = 0\cdot 5$) in the transmitter, this being automatically corrected at the receiving end. This arrangement gives a lower signal/noise ratio, and I should like to ask Mr. Blumlein whether it would be possible to reduce the γ value of the picture in the transmitting system and increase it again in the receiver.

Mr. G. E. Condliffe: I wish first to comment on the selection of 405 for the number of lines per picture. At the time when the system was decided upon by the Television Advisory Committee, this number of lines represented an advance in definition on any experimental system working on the Continent or in America. The number 405 was a compromise between ideal definition and the practical limitations imposed by the present-day transmitting and receiving equipment. It is unfortunate that the U.S.A. and Germany intend now to standardize on 441 lines, as I question whether any observer, however skilled or critical, would be able to detect the difference between two representative transmissions, one on 405 lines and the other on 441. To provide any appreciable difference, the number of lines would have to be increased to about 600. The difference between the two standards is not immediately important, since exchange of programmes between this country and the Continent is a distant possibility; but it is a definite one. Any unnecessary difference in standards is an obstacle which will tend to delay a natural and desirable development of television broadcasting.

We have our own problems in relaying television programmes to the provinces, and the recent outside broadcasts by cable and radio link are an indication of the possible successful development of the next phase in television broadcasting. The relays so far have been over distances of about 15 miles from Alexandra Palace; the problems involved in covering larger distances are greater but are clearly capable of solution. The quality of these outside broadcasts has recently been improved by removing the radio-link receiver from Alexandra Palace, where the level of interference is high, to a much quieter position at Highgate. Signals received there have been relayed by cable to Alexandra Palace. This appears to be a small-scale model of a possible national scheme in which the Alexandra Palace studios would be linked with the regional television stations by small-power radio transmitters using highly directive aerials. Sites for the transmitting and receiving aerials could be selected to give maximum range and freedom from interference, use being made of cable to link up relay receivers to the regional transmitters, or to bridge between two relay stations where it would be inconvenient and uneconomical to use a radio link.

Mr. G. C. Marris: The Emitron camera is unrivalled for studio and outside broadcasting, but I doubt whether it is the most suitable type for films.

With regard to film transmission, we have built and had some very satisfactory experience with a 405-line interlaced transmitter using disc methods. The results compare favourably with those obtained at Alexandra Palace; and, when one sees the number of correcting circuits which the Emitron camera requires, one is inclined to ask whether such disc methods may not after all have their place.

In connection with the question of the γ value of the transmission, it is as well to remember that in the early days of broadcasting there was much talk of altering the amplitude ratio, but it was felt that if a straight-line law were abandoned it would be difficult to find a standard to which to work; and I fear that this may be the case also with television transmission. At any rate, if there is to be any departure from the linear law it will require careful watching, because the difficulties affect not only the intention but also the practice. Many of us who regularly look at the pictures transmitted from Alexandra Palace feel that the value of γ wanders a good deal, particularly with certain types of transmission. If we are going to have a correction in the receivers which may also wander from its nominal value, the position may become rather difficult.

We also feel that the present methods of transmission do not give the full quality obtainable from 405-line television, and an attempt to improve the quality by the use of an appreciably greater number of lines would introduce difficulties of receiver design. As the number of lines is increased, the band width required tends to go up very rapidly, and the amplification per valve decreases, leading to greater cost of the receiver. The cost of receivers is already presenting great difficulty, and it is not obvious where drastic reductions can be made.

In the picture signals transmitted from Alexandra Palace the frame-synchronizing impulse comes immediately after the last picture line, and tends to put the whole of the black band for the synchronizing period at the top of the picture. Any variation in that portion of the transmission tends to shift the picture in the frame.

We feel that it would be easier from the point of view of receiver design if that synchronizing period came nearer the middle of the frame blank.

Although it is possible to adjust most receivers so that they interlace perfectly on the Alexandra Palace signals, I suggest that the use of added impulses at the transmitting end to predispose the receiver to interlace properly might be considered. A method of amplitude separation of signals instead of frequency separation might even be employed.

Dealing with the question of controls, the television industry needs to watch very carefully how its demonstrations to the public are carried out, because there is a great tendency, if a demonstration is conducted so that it is visible to a large number of people, to increase the contrast so as to enable people a long way away to see, at the expense of the half-tones. Receivers built for the purpose of such demonstrations are liable to be unsuitable for use in the home, or unnecessarily costly.

Mr. L. H. Bedford: Among the technical triumphs described in the papers three are outstanding, namely the Blumlein wave-form, the compensation of spurious signals by means of tilt-and-bend signals, and the choice of the 405-line standard. The last was a very bold step, in view of the circumstances existing at the time, but it has been well justified; at 405 lines the value of the entertainment receivable increases with increase of lines at a very much slower rate than does the cost. I expect 405 lines to remain our national standard for a considerable time, if not indefinitely.

It seems to me that the greatest problem of television at the moment is not technical but economic. The expenditure on programmes, which includes artistic and technical expenses, is very high, and the difficulty is, in view of the cost of receiving apparatus, to collect a large enough audience to justify them. One powerful approach to an economic solution lies in the internationalization of television programmes. If we are given a group of some thousands of viewers in England and an equal group of viewers (for instance) in France, the efficiency of the complete system is increased by a possible factor of 4 if the programmes can be "cross linked"; for in this way twice the programme material is made available to twice the audience. The implications of this international linking-up are evidently extremely far-reaching, and the problem is not beyond technical solution if, but only if, an international standardization of the wave-form numerics can be established at an early date.

There is one omission in the paper which may have caused considerable surprise; the term "Iconoscope" is conspicuous by its absence. I suggest that an explanation of the relation of the Emitron to the Iconoscope would be of interest.

Mr. P. W. Willans: Messrs. Macnamara and Birkinshaw refer to interference from sources extraneous to the receiver as constituting the limiting condition for reception. The question whether it will ever be technically and commercially possible to effect a substantial reduction in such interference by suppression at the source is one of fundamental importance and has a direct bearing upon the whole problem of television transmission. If, as at present appears probable, we cannot look forward to a drastic reduction in interference, we have to consider very carefully what type of transmission is best adapted to cope with conditions as they are now. Here, in my submission, the primary consideration is interference with the picture; the question of eliminating interference which tends to destroy synchronism raises no fundamentally insuperable difficulties, and admits of possibilities which do not exist in the case of interference with the picture.

Mr. Blumlein mentions in this connection that the question of "positive" versus "negative" modulation is still a matter of controversy. I hope that it is, at any rate, still open. The circumstances in which a decision had to be made on the transmitted wave-form, conditioned as they were by the necessity for designing and manufacturing a commercial transmitter against time, were wholly unfavourable to any satisfactory testing of the points at issue. Indeed, one may doubt whether anything but extended trials under practical working conditions could possibly give the necessary information on which a decision should be based.

I note from Mr. Blumlein's remarks that tests with inverted modulation were carried out and that with negative modulation the picture was broken up by strong interference. It would be interesting to learn more about these tests and, in particular, whether the receivers employed in them were all of one type or whether different synchronizing and scanning arrangements were tested against each other. I should also be glad to know whether the interference, in the case of negative modulation, consisted predominantly of black dots (in contrast with the case of a positively modulated transmission employing a receiver equipped with a simple limiter, to avoid the effect of excess modulation of the cathode-ray tube). Statistically speaking, this would appear probable.

It is to be remarked that any system with "negative modulation" [not merely that specifically referred to in Section (5), page 759] offers the possibility of simple automatic volume control at the receiver. This must be reckoned as an advantage.

My basic argument in favour of allowing the interference to be predominant on the synchronizing side lies in the fact that synchronizing signals are (or should be) strictly repetitive and the intelligence which they are required to transmit can be the result of their cumulative effect. To take a simple example, if a harmonic constituent of the synchronizing signals is selected at the receiver and made to do the work of synchronizing, interference should clearly be very much reduced, and this step may be supplementary to anything that is done by way of limiting the amplitude of the pulses.

I feel that interference difficulties may be worse in the case of scanning oscillators of the type that can be easily triggered off "out of time." I have no liking for the type of scanning system which, so to speak, has to be told at the end of every line when to "fly back." It seems far more logical to go to the other extreme and use scanning oscillators which can be governed easily by truly repetitive synchronizing impulses and not so readily by signals occurring at irregular intervals. But, admittedly, the synchronizing signals must then be truly repetitive. In this connection I am interested to note the developments in the timing system described in connection with Fig. 8 (page 771). The mechanical master-frequency generator, as far as its objects are concerned, represents an advance,

but it may well be possible to produce the desired results by electrical means, namely by a system that follows the long-period frequency variations of the mains while ignoring variations of short period.

Mr. R. C. Ballard's patent dealing with interlaced scanning is referred to in Mr. Blumlein's paper. I am bound to say that the inventor appears to be somewhat over-sanguine. According to the patent specification, all that is necessary is to connect up a receiver, apply the line-frequency synchronizing impulses on to one scanning oscillator and the frame-frequency impulses on to another, and perfect interlacing will follow. In practice it appears that special precautions are necessary to produce the required result, but at present these have to be taken at the receiver, as is indicated by British Patent No. 455375 (due to Mr. E. C. Cork and other E.M.I. engineers). In view of the fact that the Marconi–E.M.I. Television Co. control another British Patent, No. 448065, with which troubles with synchronizing of the kind dealt with in Mr. Cork's specification are stated to be avoided, it seems unfortunate that the burden should be placed on the receiver designer.

Mr. Blumlein tells us that in the present transmission we have 5 unused lines at the end of every picture-frame before the transmission of a low-frequency synchronizing signal; we gather from Mr. Condliffe's remarks that an increase in the number of picture lines from 405 to 441 will not give any perceptible improvement in the detail of the picture, so that 5 lines more or less will make no difference, but still Mr. Blumlein considers that these lines should be used as picture lines and proposes to make the necessary alteration for this purpose at an early date.

I should like to plead for consideration of the proposals of Mr. A. V. Bedford (British Patent No. 448065) according to which preparatory signals, of double line frequency, are sent out immediately before the low-frequency signal so that the receiver "does not know the difference" between an odd and an even frame. The advantage, if achieved, would far outweigh the loss of picture lines entailed.

(*Communicated*). In the July, 1938, number of *Electronics* (page 28), particulars have been published of the U.S.A. television standards, and it is interesting to note that negative modulation is recommended (together with positive synchronizing impulses) and also that so-called equalizing pulses are transmitted before and after the vertical synchronizing signal. These equalizing pulses are of double the line frequency and appear to conform to the proposals contained in British Patent No. 448065, to which I referred in the discussion. It is to be presumed, at this stage of development, that these standards have been adopted with due regard to the results obtained in this country and with full knowledge of any dangers that may exist of synchronization being adversely affected.

Mr. F. R. W. Strafford: I wish to make one reference to Mr. Macnamara's remarks about the transmitting aerial used with the mobile equipment. He said they were surprised to find that there was no reciprocity between the two methods of effecting the transmission, by using a high transmitting aerial and a low receiving aerial or vice versa. I should like to point out that the question of reciprocity between aerial systems applies only under the ideal mathematical postulation of free-space conditions, and that the behaviour of an aerial when fed with current is entirely different from its behaviour when receiving a signal, because of the difference in the distribution of current. In the case of the transmitting aerial the current is applied at a point, whereas the receiving aerial is in a uniform field. The different current distribution gives rise in many cases to different directional properties. The effect upon an aerial of the proximity of earthed conducting objects is different when the aerial is transmitting from that produced if the aerial is receiving; because, if the objects are close enough, in the case of reception the aerial is in a pure radiated field, whereas in the case of transmission it is in an inductive field.

(*Communicated*) Since making these remarks I have had an excellent opportunity of conducting certain practical tests which confirm, without any possible doubt, these assumptions.

Dr. L. E. C. Hughes: The symbol gamma refers to the slope of the curve representing the brightness of the reproduced picture in relation to the brightness of the original, and, in photographic terms, measures the contrast. Theoretically the overall gamma value should be unity, so that the reproduced contrast is the same as in the original; if the average brightness of the reproduction is deemed to be correct, then the gradation will be natural. The adjustment of both the average brightness and the contrast should be in the hands of the user, so that by turning knobs he can adjust these variables to suit his particular conditions of ambient illumination, just as various degrees of tone-control should be available in sound-broadcasting reception. The justification for any such adjustment to the taste of the user resides in the fact that the systems are not perfect; if they were, the engineer having complete control over the entire transmitting and receiving system, there would be no case for arbitrary adjustment. The sound-broadcast is not perfect because of various interferences, and the user has a case for asking for a control which enables him to arrive at the best sample of reproduction he can get in the circumstances. In like manner, a contrast-control is as essential in a television receiver as a brightness-control. The television system is not perfect, in that colour is lacking. In cinematography, this lack of colour is compensated by increasing the overall gamma of the projected picture and by moulding the figures and objects on the set with clever lighting. In normal cinemas, the overall gamma appears to be about 1·4 to 1·6, and in amateur work the value may rise to 1·7. The only way to achieve technical stability in television, where the operation of the receivers is not in the hands of the transmitting engineers, as it effectively is when high-grade release prints are being made for cinemas, is to arrange for the transmitting gamma to be equal to unity and to leave the increase to the taste of the recipient. The overall-gamma adjustment should not be the responsibility of the engineer, until the system has been perfected to such an extent that the question cannot arise.

The existing prevalent size of picture would seem to be inadequate. The optimum width of angle of vision appears to be, from experience in cinemas, that obtained at a distance equal to four widths of the screen. It is evident from experiments with opera glasses that widening the picture only a moderate amount greatly increases

the interest, indicating that the potentiality of definition is in the system, but is not used because of the smallness of the picture in normal viewing conditions. When one experiences a picture of the normal programme some 5 ft. wide, the interest becomes so great that varying defects of the cameras are forced on one. Incidentally, it appears that no amount of public demonstration is likely to increase the permanent public interest in television, mainly because of the psychological atmosphere. Personal experience in the home without distractions is likely to be more effective in building a television audience. This is realized by firms who are willing to hire a receiver for a week or so at a nominal charge.

On the programme side, it is surprising that the B.B.C. has not used film for its own items. There is considerable value in "shooting" the required images on film for subsequent telecinė scanning, as it permits artists to make the images at greater convenience. These images can be made at any studio available without congesting the floor for the impromptu work, and this technique permits a degree of editing which is realized to the full in cinematograph work. Can it be claimed that the public prefer artistic performances which are liable to go wrong, because of long sequences, to the more perfected version which could be obtained by film methods? With the present standard of transmission, film economy is available in the use of sub-standard stock.

Mr. K. S. Davies (*communicated*): In the sound broadcasting service, transmitter development has been able to proceed continuously from its inception without affecting in any way receivers already in use. But in television the transmitter and receiver are much more closely inter-related and, in deciding upon television standards, the fact must be borne prominently in mind that once the service has been established, and a considerable number of receivers are in use, it will be very difficult to make any radical alteration in the system of transmission. The selection of the wave-form to be transmitted in a national television service thus places a very great responsibility upon those who are entrusted with the choice.

After nearly 2 years' experience of the working of the London Television Station we have every reason to believe that the choice has been wisely made. While very good pictures are being transmitted at the present time, one has only to examine an electrically transmitted photograph of an equal number of lines to see that considerable room has been left for improvement within the present standards.

The use of interlaced scanning has yielded a very good solution to the problem of eliminating flicker without increasing the transmitted band-width, and the "odd-line" method actually employed has an added advantage in that the amount of apparatus in the time-base circuits is not increased. The successful use of odd-line interlacing does, however, call for very precise synchronizing of the frame time-base. It has been suggested that the lack of symmetry between the signals at the ends of the odd and the even frames in the present transmissions is responsible for the faulty interlacing of many commercial receivers. This asymmetry, however, can only affect such receivers as rely on integration as the means of frame-impulse selection, but both theoretical and practical considerations show that satisfactory performance can hardly be expected from this type of circuit. For the impulse obtained from an integrating circuit must necessarily be of very rounded wave-front and thus cannot ensure the exact timing of the frame time-base which is essential.

For this reason, I believe, one of the experimental systems at present being very successfully used in America employs amplitude separation between the line and frame impulses. The chief advantage claimed for this system is that the frame impulse can be given the same steepness of wave-front as the line impulse, so that the required accuracy in timing is readily obtained.

But it is possible in the case of the present transmissions from the London Station to obtain a precisely similar result, and by the use of no more apparatus in the receiver than would be required for amplitude discrimination. This method depends upon the use of the trailing edge of the first of the eight frame impulses, which can quite easily be selected, and which affords a frame-synchronizing impulse equal in steepness to a line impulse.* Mr. Blumlein points out the advantages of working in such way that all synchronizing impulses reduce the carrier to zero. With amplitude separation either the line or the frame impulse must be represented by a finite value of received carrier, and therefore one or other of the time-bases will be rendered more liable to disturbance by strong interference. It appears, therefore, that amplitude separation can offer no advantage over the method at present in use and, further, that no modification of the existing wave-form can be expected to effect either an appreciable reduction in cost or an improvement in performance of commercial receiving sets.

Mr. H. G. M. Spratt (*communicated*): It would be interesting to know whether the smoothing and impedance-matching in the mobile van equipment is of the same standard as that at Alexandra Palace, and, if so, how it was possible to dispense with a 500-cycle supply.

Mr. Blumlein stated that the absence of identical preparatory signals before each frame-synchronizing train of pulses was a disadvantage only in a comparatively few limiting circuits where the time-constant during the synchronizing pulses was shorter than that during the remainder of the line. This statement appears to justify the insertion of one line at least having two line-pulses at half-line intervals before the train of frame pulses. The extra complication thus involved in the pulse generators should be negligible. Furthermore, it cannot be argued that no room exists for these pulses, seeing that at present 5 blank lines are transmitted before the frame-synchronizing train and in any case the maximum interval between frames is fixed at 10 lines. In view of the greater flexibility in limiter design which this modification would provide, I should be glad to know why it has not been carried out and is apparently not contemplated.

Mr. J. C. Wilson (U.S.A.) (*communicated*): I shall confine my comments to the paper by Messrs. Blumlein, Browne, Davis, and Green.

The discussion of reasons for the choice of a gamma value of unity in the transmitter [Part I, Section (3)] is incomplete; if it is desirable to apply correction at the

* H. A. Fairhurst: British Patent No. 484412.

receiver to raise the gamma value to about 1·6, on account of the relative diminution of the effect of small parasitic receiver noises thereby obtained, then *a fortiori* it is advantageous to make use of a transmitter modulation characteristic corresponding to a gamma value less than unity, the better to override channel noise. The utility of this for radio transmission is well known and has been demonstrated in practice.* As a matter of fact, by a fortunate accident the iconoscope (or Emitron) is adapted to give the same advantage in overriding ultimate valve and thermal noise at the start of the vision

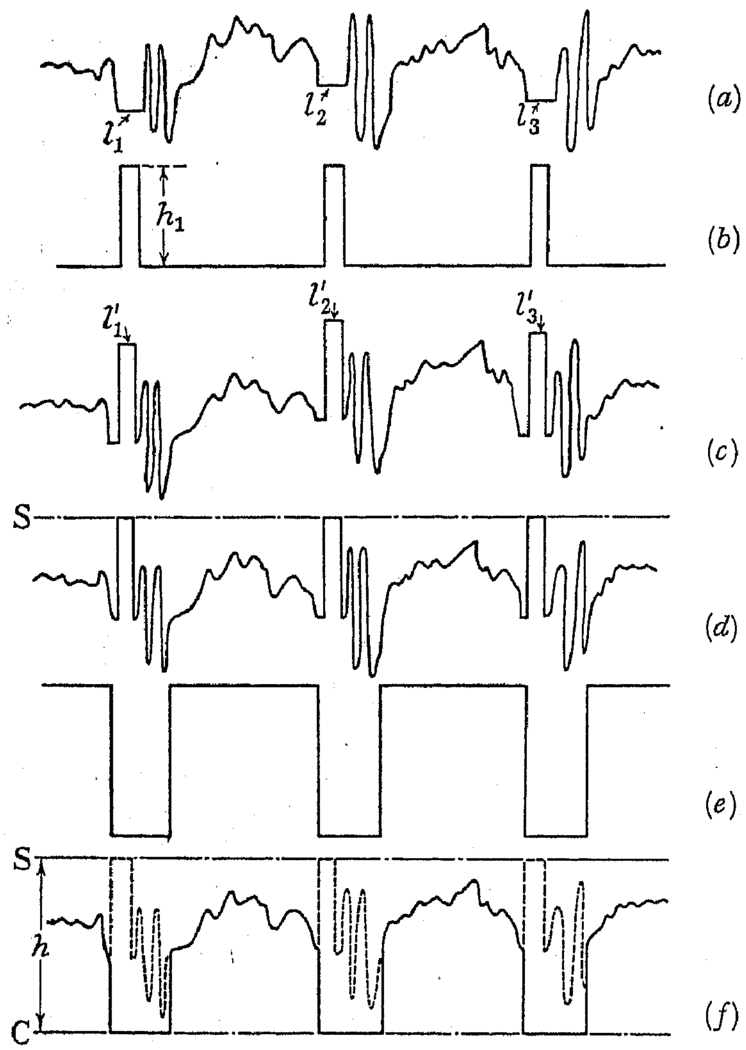

Fig. A

channel, in that it exhibits a markedly curvilinear brightness/signal characteristic, the curvature being in correct sense.†

To call the use of the "blackest" signal derived from the picture for level-locking "in some respects a compromise" [Part II, Section (4)] is euphemistic, to say the least. It is surprising that the authors adopt this view, and method, having regard to the fact that convenient and much more acceptable ways of keeping the black level at true or "picture black" are available. For instance, with reference to Fig. A, consider the video signal, complete with surge components, proceeding from the camera, as shown at (*a*), in which datum levels l_1, l_2, l_3, etc., have been inserted bearing a fixed relation to "picture-black" (for example, by running the scanning beam on to a plain metal strip of uniform secondary-emissive properties independent of the image brightness falling on it, at the termination of each scanning line); after passing of the signal through a portion of an amplifying system the levels l_1, l_2, and l_3 will, of course, generally lie at different voltage heights, as shown, owing to loss of d.c. and low-frequency components. To this signal is added, in timed relationship, the constant-amplitude pulses (*b*), resulting in the combined wave-form shown at (*c*), in which the levels l_1, l_2, l_3, etc., are represented by new levels l_1', l_2', l_3', etc., lying outside the range of voltage ordinates occupied by the video and surge components.

The signal can now be stabilized* on the tips of the injected pulses which align themselves on the S-level as shown at (*d*). A blanking wave-form of the type shown at (*e*), of sufficient amplitude to swamp the surge and injected pulse components completely, is then combined with the stabilized wave in such a manner as to run a valve of the system to cut-off at the level C, as shown at (*f*); the rectangular portions of this wave are then prepared for receipt of the synchronizing pulses or other information as desired. Moreover, if the instantaneous signal value represented by the original levels l_1, l_2, l_3, etc., with respect to true or "picture-black" is h_2 and the equivalent voltage-height of the (*b*)-pulses is h_1, then the level C will represent the proper tone of black if $h = h_1 + h_2$, where h is the equivalent voltage-separation between the S-level and the C-level.

That reference to some such proper method of level-locking should have been omitted in the paper and replaced by an improper one is all the more surprising because the method just described is somewhat similar to that given in Reference (2), page 779.†

It may be objected to the method described that it involves the insertion of a signal-segment of standard level during the strip underlap interval, where time is already severely limited by the difficulty of obtaining a fast enough retrace stroke in the scanning circuits, having regard to the length of cables required for studio operation, etc. Also it requires that registration of the scanned area with a particular portion of the matrix in the camera shall be very exact. The former difficulty is one of degree and expense, and in relatively complex and expensive transmission installations the necessary measures can be taken. The latter difficulty is avoided by making the level-inserting element (copper strip or the like) in the tube play a part also in the scanning operation, so that the scanned area automatically aligns itself, like a company of soldiers dressing by the right against a brick wall.

With regard to the choice of positive polarity of transmission [Part I, Section (14)], there are many confusing arguments to be brought up for and against, a majority of them depending upon questions of degree. It has been pointed out, however, by Mr. H. M. Lewis, whose view I adopt, that an absolute advantage in favour of negative polarity lies in the fact that with positive modulation as ordinarily practised there exist only two available reference levels in the received signal (namely zero-carrier and the blanking or "black" level), whereas with negative there are three (zero-carrier, blanking, and peak-power levels). The extra intelligence inherent in a negatively modulated signal, including the d.c. component,

* R. C. Mathes and S. B. Wright: *Bell System Technical Journal*, 1934, vol. 13, p. 315.
† V. K. Zworykin, G. A. Morton, and L. E. Flory: *Proceedings of the Institute of Radio Engineers*, 1937, vol. 25, p. 1071.

* J. C. Wilson: "Television Engineering" (Pitman), p. 348.
† British Patent Specification No. 450675.

in the long run overweighs the transitory advantages of positive transmission. Amongst other uses it has the obvious one of providing a peak reference level for obtaining automatic volume control in a simple manner at the receiver.

A small correction is required in connection with Fig. 1, in which no time-interval is shown before the commencement of frame-synchronizing pulses, whereas in Part I, Section (13), it is stated that five additional " black " lines are put in before the synchronizing pulses.

THE AUTHORS' REPLIES TO THE DISCUSSION BEFORE THE INSTITUTION

Messrs. T. C. Macnamara and **D. C. Birkinshaw** (*in reply*): Sir Noel Ashbridge mentioned one or two economic differences between sound broadcasting and television, and in this connection it is interesting to compare the present situation as regards rehearsals. In the case of a production over the sound broadcasting system some 5 hours of rehearsal are necessary per hour of transmission. It will be at once evident that in the case of television at least this, and preferably a greater, ratio of rehearsal to transmission time is required, since the rehearsal involves, in addition, the setting of lights, considerations of make-up and costume, and, moreover, artists cannot read their parts from scripts. At present, rehearsal/transmission time ratios of only 1 or 2 to 1 are being realized, and although a great deal can be done by means of preliminary rehearsals conducted without apparatus, it is essential, if the standard of presentation is to be improved, for facilities to be provided enabling more rehearsal time to be spent in the studio. It is primarily for this reason that a second studio has recently been put into service, and a third is at present in the course of being prepared at the Alexandra Palace.

Mr. Gill referred to the work that the B.B.C. is doing on the use of telephone circuits for television purposes. In this connection it is interesting to note that it has already been found possible to send vision signals over a length of 4 miles of ordinary telephone circuit. The technical arrangements necessitated the use of special terminal equipment, and of two intermediate repeaters with equalizers installed at the two Post Office exchanges en route. It was, however, unnecessary to interfere with the lines themselves. We should like to record the fact that the London Telephone Service has been most helpful in providing the necessary facilities for experiment in this direction. The transmission of television signals over normal telephone circuits is considered to be a useful method of extending the number of possible television outside broadcasts which can be carried out with the aid of the balanced cable circuit, and, if successful results are consistently achieved, there will, no doubt, be ample justification for an extension of the balanced cable.

It is also considered that the potentialities of the radio link between outside broadcast points and the London Television Station are capable of further development, which should lead to an extension of the maximum distance from the Alexandra Palace at which it is now possible to handle such broadcasts, and which is now some 15 miles.

Mr. Marris raises an important point when he refers to the question of demonstrating television receivers to the public. The television receiver designed for home use cannot be successfully seen by a large number of people at once, and, where this is attempted, the overloading of the tube, due to the use of an excessive contrast adjustment, will inevitably give those nearest to the receiver an unfavourable impression of the picture. We consider that, with the receivers available at present, the maximum number of people who can simultaneously and satisfactorily see a picture is not much greater than 12.

Mr. Bedford very rightly refers to the difficulty created by the high cost of television programmes, and suggests as a remedy the " internationalization " of programmes. This is certainly an attractive possibility, but it is, of course, subject to many difficulties both technical and non-technical, the latter including the question of differences of languages. If the technical difficulties can be overcome, however, it might be found possible to devise a proportion of television programme material which would carry its entertainment value in the picture rather than in the sound, and would therefore be acceptable to an international audience.

Mr. Willans made reference to the question of interference from sources extraneous to the receiver, and is not optimistic as to the possibility of any improvement in this respect. In view of the fact that such interference largely emanates at present from motor-car ignition systems, it does seem to us that some amelioration of this difficulty could be obtained by negotiation and, possibly, by legislation. As regards the relative effect of the interference on the picture and on the synchronizing, the system was designed so that interference would manifest itself primarily on the picture, and that no serious effect on the synchronizing would be observed until the picture had been rendered unacceptable by interference. As a result of many observations it is considered that the design of the system is satisfactory in this respect.

Concerning Mr. Strafford's remarks upon the subject of reciprocity between aerial systems, we agree that further experimental work is needed to determine the conditions in which reciprocity applies to systems employing ultra-short waves. The point is rather that the absolute level of interference received with a high receiving aerial may be greater than with a low aerial. This is an entirely separate matter which may complicate the issue but has no bearing upon the principle of reciprocity, although the conclusion is that more favourable results are likely to be received with a high transmitting aerial and a low receiving aerial than vice versa.

Dr. Hughes made some observations upon the most desirable size of a received picture. It will be generally agreed that an increase of picture size is desirable but it should be remembered that this will bring certain problems to those responsible for the transmissions. It is already known that the studio technique which should be adopted in production is considerably influenced by the size of the reproduced picture. With the size at present available it is found desirable to employ what may be described as an intimate production technique, but observations which have been made with comparatively large received pictures show that such a technique

is not suitable for such pictures, and there is no doubt that when the public are generally equipped with large picture receivers the studio technique will be quite different from that employed to-day. An interesting problem therefore arises in the intermediate period when some viewers have provided themselves with modern large-picture receivers, while others still retain the types in use to-day.

Dr. Hughes also mentions the question of the B.B.C. "shooting" its own film. It is improbable that it will be found desirable to introduce film as an intermediate stage in the production of the general run of television programmes, but there is a considerable field in the employment of specially-taken films to supplement normal productions and introduce into them scenes which could not be conveniently set up in the studio. In this connection, it should be mentioned that the B.B.C. has for some time been "shooting" a considerable amount of film for this purpose.

Messrs. A. D. Blumlein, C. O. Browne, N. E. Davis, and **E. Green** (*in reply*): A number of speakers have raised the question of the best γ value to use, and the advisability of introducing preparatory signals before the frame-synchronizing signals. These points will be dealt with first, before the remarks of individual speakers are replied to.

Messrs. Gill, Hughes, and Wilson, have suggested that a lower γ value than unity might be used at the transmitter, and subsequently corrected at the receiver. It might be argued that the human eye has an almost logarithmic sensitivity and so desirably the transmitter modulation should be a logarithm of the original brightness, the receiver having an exponential characteristic so that background "noise" would be equally noticeable at all levels. However, for a picture viewed as a whole, the eye does not appear to have logarithmic sensitivity as regards noticing low-level interference. If a television picture is examined with low-level interference introduced in such a manner as to be modified by a γ of about 2 when converted to light intensities, it will be noticed that the interference is hardly more noticeable in the blacks than in the whites, provided, of course, that the focus is maintained for the high lights. This latter requirement is important since in practice the surface noise in the high lights is usually obliterated by the less perfect focus of the cathode-ray tube. This leads to the conclusion that a slight theoretical improvement might be obtained by working with a transmitted γ slightly less than unity. The practical return would be almost negligible since near the optimum the curve of advantage is flat-topped. Further, it must be remembered that a very high γ at the receiver makes intense interference (such as motor-car interference) appear very objectionable.

Messrs. Marris, Willans, Spratt, and Wilson, have asked for preparatory signals before the frame-synchronizing signal. Mr. Davies does not want them, nor presumably does Mr. Bedford. It must be pointed out again that we know of only one type of circuit which is the better for preparatory signals, whereas there are a number of circuit types where such signals are quite unnecessary. Mr. Willans has referred to one, and Mr. Davies has pointed out the extremely elegant type due to Mr. Fairhurst. Using the integrating-type circuit without preparatory pulses, the interlace is slightly misplaced, but our practical experience is that any real trouble in interlacing is usually due to coupling between the scanning generators, which would be completely unaffected by the preparatory signals. Mr. Spratt has suggested two lines of preparatory signals, whereas apparently Mr. Willans requires perfection. To give a good result with a true integrating circuit (very long time-constant) a very large number of preparatory lines are required, perfection being achieved when the whole frame period is used in preparation for the frame-synchronizing pulse and no time is wasted in picture transmission. In practice a fair number of lines must be utilized for preparatory pulses if they are to be worth sending at all. This time is therefore wasted, as it is not used either to accommodate the receiver flyback or to give the receiver time to recover from any slight upset of line scanning due to the latter having been triggered by frame-synchronizing pulses. Mr. Willans is astonished that an attempt should be made to improve the efficiency by 5 % by reducing the frame interval from 20 to 10 lines, whereas Mr. Condliffe is sure that a change from 405 to 441 lines would produce no noticeable improvement of picture. Of course, such a change accompanied by a 20 % increase of band width would give a better picture. However, for a given band width (be it that appropriate to 405 or to 441) a 10 % change in number of lines would slightly interchange horizontal and vertical definition, and would produce negligible change in picture quality. The increase of 10 picture lines in each frame means a 5 % improvement without increase of band width.

Mr. Willans finally points out that the new U.S.A. television standards include preparatory pulses not only before but gratuitously after the frame-synchronizing pulses, and that this standard is presumably the result of much consideration. It is to be noted that the new German standard,* presumably decided upon after similar consideration, does not employ any preparatory pulses. Mr. Ballard's patent may appear sanguine but it has the right idea, and it must be repeated that the practical difficulties are usually due to stray couplings which prevent the scanning generators running uniformly as required by the Ballard arrangement.

It was appreciated that it would be possible to construct a mechanical film transmitter, but the correcting circuits to which Mr. Marris refers for the Emitron film transmitter are already part of the system and are used, of course, for all cameras. The Emitron film transmitters are synchronized from a centralized source of timing signals so that they may be mixed with the studio cameras if required, whereas it is well-nigh impossible to synchronize a mechanical transmitter with sufficient accuracy to provide the same facility. A solution to this difficulty is to use the mechanical transmitter as the source of timing signals, but, even so, the immediate disadvantages are obvious, and this method does not lend itself kindly to an extension of the television station with further studios each with the necessary camera control equipment.

Mr. Marris has suggested a consideration of amplitude selection for frame- and line-synchronizing signals. This

* D. von Oettingen, R. Urtel, and G. Weiss: *T.F.T.*, 1938, vol. 27, p. 158.

system demands that not only must the vision signals lie totally on the straight part of any amplifier, modulation, or detection characteristics, but similarly the synchronizing signals must lie on linear portions of the characteristic. With positive modulation using zero carrier for the larger synchronizing pulse, the modulation and detection are extremely difficult if the larger synchronizing pulse is not to be crushed. With negative modulation all the advantage of a simple line-to-line A.V.C. is abandoned.

In answer to Mr. Bedford's question regarding the relation of the Emitron to its American counterpart, the Iconoscope, it should be stated that these are trade names and apply to two entirely independent developments of the cathode-ray tube for transmitting images proposed by Campbell Swinton in 1908.*† Because the same fundamental principles are involved in the two tubes, it is not surprising that they should be generally similar in physical appearance, but the differences of the two tubes which are now known to exist are accounted for by the dissimilar methods adopted in their manufacture.

With regard to the "Super-Emitron," this is a further development of the Campbell Swinton idea, but it involves an entirely new principle and was first developed in the E.M.I. laboratories.‡ This new principle has been adopted in the American version of the tube, which has been called the "Super-Iconoscope."

Mr. Willans feels that negative modulation may still be the correct solution. As regards the tests referred to in the first part of the paper, the receivers used for testing negative modulation had no special limiter to limit interference in the receiver output to a value corresponding to the peak synchronizing amplitude. The time-base, however, was designed to be quasi-periodic, in that the scanning generators were only capable of being triggered by an incoming pulse shortly before the end of the scanned line. Even with a critical adjustment, interference tended to cause a "ragged" picture, even if incapable of seriously displacing the lines. It is agreed, of course, that suitable limiters can make negative and positive modulation practically equivalent, but such limiters are a necessity with negative modulation, and it is the cheap receiver (without A.V.C.) which must be kept cheap.

The impedance-matching of the circuits used in the modulation amplifiers for the mobile transmitter, to which Mr. Spratt refers, is carried out with the same care as for the modulation amplifiers described in this paper. The mobile transmitter, however, is of considerably lower power, and so requires less swing from the modulation amplifiers. It was therefore more economical to provide larger smoothing components and to increase the power-handling capacity of the amplifiers to produce the swing required, than to install a 500-cycle supply.

Mr. Wilson elaborates a method of d.c. establishment which is agreed to be essentially the same as that described in Reference (2) of the paper, but these and similar methods suffer from the disadvantage that the reference signal is generated at the edge of the picture where the tilting conditions are sometimes difficult. The method of establishment of the direct component from a black border as described in Reference (2) has been used experimentally for film transmission, and by using the circuits given in Reference (12) the result was obtained without the complication of the method Mr. Wilson proposes.

Mr. Wilson's argument for negative modulation appears to be that it provides a means by which the amplitude of the synchronizing signals can be checked in terms of the difference between black level and zero carrier, which incidentally cannot be peak white unless perfectly linear modulators and detectors are invented. There may be a use for three reference levels, but the use is not obvious.

As regards Mr. Wilson's final remark, it is pointed out in Section (*e*) of the Appendix to Part I that the 10 lines are a minimum interval, and in Section (*m*) that initially this minimum may be exceeded. Also, in Section (13) of Part I it is explained that ultimately it is hoped that the 10-line interval will be realized.

* *Nature*, 1908, vol. 78, p. 151.
† *Journal of the Röntgen Society*, 1912, vol. 8, p. 1.
‡ H. G. Lubszynski and S. Rodda: British Patent No. 442666.

THE TWENTY-NINTH KELVIN LECTURE

"STATISTICAL LAWS OF NATURE"

By PROFESSOR MAX BORN, M.A.

(*Lecture delivered before* THE INSTITUTION, 28*th April*, 1938.)

INTRODUCTION

The field of my own work is so very remote from electrical engineering that I felt some difficulty in choosing a subject for this lecture. I have been chiefly engaged in research on abstract and general theories which can be adequately formulated only with the help of a fair amount of higher mathematics, whereas I imagine that most of you are chiefly interested in practical problems. But we have a common interest in the work of Lord Kelvin, a brilliant physicist and an eminent engineer, who worked at the same time on the most abstract questions of science and on their practical application. He gave many examples of how to apply newly-discovered laws of nature to technical purposes, and he was one of the last scientists who were able to do original work in both spheres. To-day the scope of science and technology is so enormous that no single individual is able to cover both fields.

Engineering consists in the application of physical laws, and therefore it seemed to me appropriate to draw your attention to one of the most important changes which the interpretation of these laws has undergone of recent years, namely the introduction of the conceptions of chance, probability, and statistics into physics. While chance is the essence of arbitrariness, it is well known that even chance has its laws, expressed by the mathematical discipline of probability. Many institutions of our social and economic life—not only the Bank of Monte Carlo, but all services which deal with great numbers of individual cases, such as administration, business, or insurance—are based on the laws of probability and rely on predictions from them just in the same way as the physicist or the engineer rely on their predictions from natural laws. It would therefore seem as if there were two different types of laws from which we could derive predictions; but the natural philosopher resents such a dualism, and the development of science has in fact justified his doubt. It has been found that laws of nature which appear to be universally true are really an outcome of a very high degree of probability. Statistical methods have been adopted more and more widely in science, and to-day the physicists are convinced that all laws of nature have a more or less statistical character. This fact has immediate applications to practical problems with which the electrical engineer is concerned. The most brilliant result of the application of modern statistical theory in physics is the explanation of the properties of that class of materials with which the electrical engineer has chiefly to do, namely the metals—their strength, electrical conductivity, and thermic and magnetic behaviour. Moreover, the electric discharge tubes used for advertising purposes, rectifying and amplifying valves, and many other recent developments, can only be understood on the basis of statistical methods. I shall try to outline in this lecture this development of modern physics.

THEORY OF CHANCE AND PROBABILITY

What is chance? I have head the following answer to this question: "Chance is the explanation of other peoples' successes." You will agree that this definition does not suffice for scientific purposes. As scientists let us attack the question from the empirical side, let us consider how probability enters into practical problems, approaching step by step the general conception.

The simplest examples of chance and probability are provided by all kinds of gambling, e.g. throwing dice or tossing a coin. The latter game is certainly the simplest possible; if we understand it thoroughly we have the clue to even the most complex probability problems. There are people who go to Monte Carlo with "a system" whereby, they think, they can make sure of winning. They do not win, of course, and it is therefore clear that there must be a fundamental mistake. Such people behave as if by studying chances they could predict the single future event. They expect, for instance, that after a series of *rouge* there is a greater chance for *noir* at the next round; which is evidently wrong, the probability always being $\frac{1}{2}$ for *rouge* as well as for *noir*. Similar remarks apply to "head" and "tail" of a tossed coin. The idea of chance implies that the question "Will the next toss be tail?" is meaningless, as, so far as we can ascertain, no physical conditions exist which would decide in favour of one or the other side of the coin. The deterministic question is not applicable: we express the complete indeterminacy of two cases by saying that the probability of each is $\frac{1}{2}$.

The generalization of this is obvious and well known. In the case of a "perfect" die we have 6 cases of no physical distinction, and we therefore speak of the probability $\frac{1}{6}$ for each of them. This is an arithmetical definition. Of what use is it? The knowledge that two events have the same probability of happening is, of course, of no direct use at all. But it becomes useful through the possibility of repeating the experiment under the same conditions; for in doing this one gets an ever-increasing number of cases, the probabilities of which can be mathematically computed from simple rules which express the equality and the independence of the conditions. Among these cases there are some of extremely small and others of extremely high probability. Now, it is a fundamental principle—not of science, but of life—that a very great probability (expressed by a number

very near to 1, or 100 per cent) is regarded as a "practical certainty." Look, for instance, at Fig. 1; it shows a quadratic arrangement of 100 balls, 99 white and 1 black.

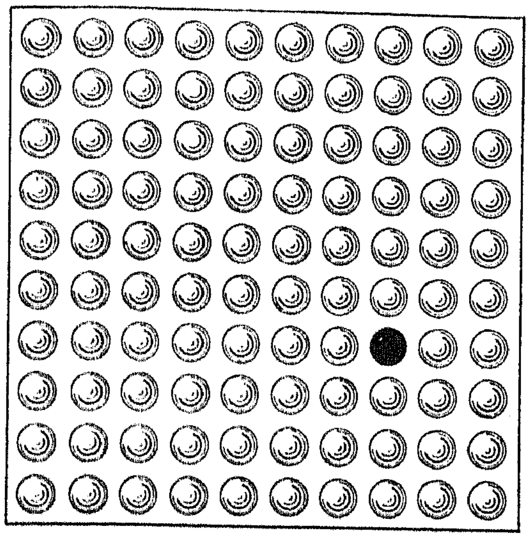

Fig. 1.—One chance in a hundred.

If you shook these balls in a box and then took one out, "by chance," would you not be "pretty sure" that it would be a white one? Life would be absolutely impossible without this identification of high probability with "certainty." We make use of it not only when gambling, or taking out a life policy, but even when we travel in a railway train—we know that a certain number of accidents occur, but it is too small to be considered.

Which approach to the unit of probability will be regarded as "practical" certainty, 99 per cent, as suggested, or perhaps 99·9 per cent, depends on the circumstances—the personal experience, taste, inclination. We shall see immediately that the combined probabilities which occur, for instance, in the repeated tossing of a coin, lead to very great probabilities, expressed by the quotient of two enormous, nearly equal numbers. These numbers are sometimes high powers: we remember, for example, the story of the inventor of chess, who asked the king to reward him by putting a grain of wheat on the first field of the board, two on the second, four on the third, and so on. At this rate there would be 2^{63} grains on the last field—more, in fact, than all the wheat ever grown on the earth. In other cases these large numbers are factorials: thus $2! = 1 \times 2$, $3! = 1 \times 2 \times 3$, and so on. The first 10 factorials are shown in Table 1. To illustrate these numbers let me tell the story of a group of 7 friends who used to have dinner together and wished to be placed at table in such a way that the order would be changed every day. Since $7! = 5\,040$, they could continue changing neighbours for about 15 years. If the number of friends in the party had been 12, they could have gone on for about 550 years!

Table 1

$1! = 1$	$= 1$
$2! = 1 \times 2$	$= 2$
$3! = 1 \times 2 \times 3$	$= 6$
$4! = 1 \times 2 \times 3 \times 4$	$= 24$
$5! = 1 \times 2 \times 3 \times 4 \times 5$	$= 120$
$6! = 1 \times 2 \times 3 \times 4 \times 5 \times 6$	$= 720$
$7! = 1 \times 2 \times 3 \times 4 \times 5 \times 6 \times 7$	$= 5\,040$
$8! = 1 \times 2 \times 3 \times 4 \times 5 \times 6 \times 7 \times 8$	$= 40\,320$
$9! = 1 \times 2 \times 3 \times 4 \times 5 \times 6 \times 7 \times 8 \times 9$	$= 362\,880$
$10! = 1 \times 2 \times 3 \times 4 \times 5 \times 6 \times 7 \times 8 \times 9 \times 10$	$= 3\,628\,800$

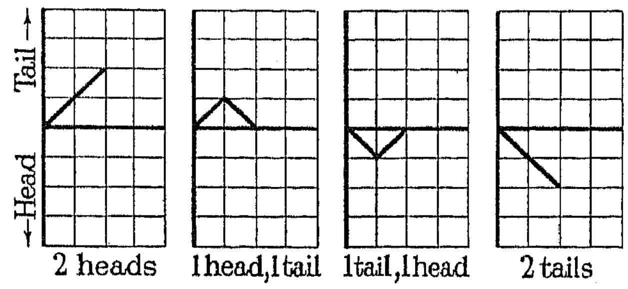

Fig. 2.—Tossing a coin: 2 tosses.

Now I want to illustrate the conception of a combined probability, with the help of the case of tossing a coin, head or tail. For this purpose I use a graphical representation. The abscissae represent the numbers of tosses, and the ordinates represent: upwards, heads; downwards, tails. Each toss is represented by a line inclined at 45° from one integer point to its neighbour, either upward

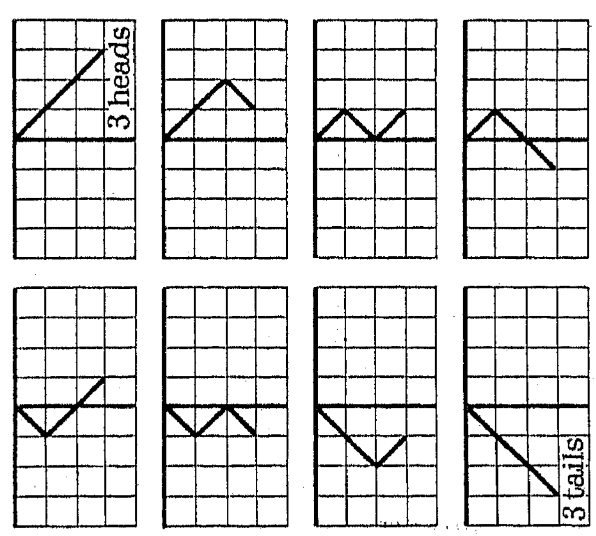

Fig. 3.—Tossing a coin: 3 tosses.

(meaning heads) or downward (meaning tails). For 2 tosses there are 4 possibilities, as shown in Fig. 2. But if one counts only the total number of heads and tails,

the two middle cases are identical. Taking this into account, there are apparently 3 cases:—

2 heads, with the probability $\frac{1}{4}$;
1 head, 1 tail, with the probability $\frac{2}{4} = \frac{1}{2}$;
2 tails, with the probability $\frac{1}{4}$.

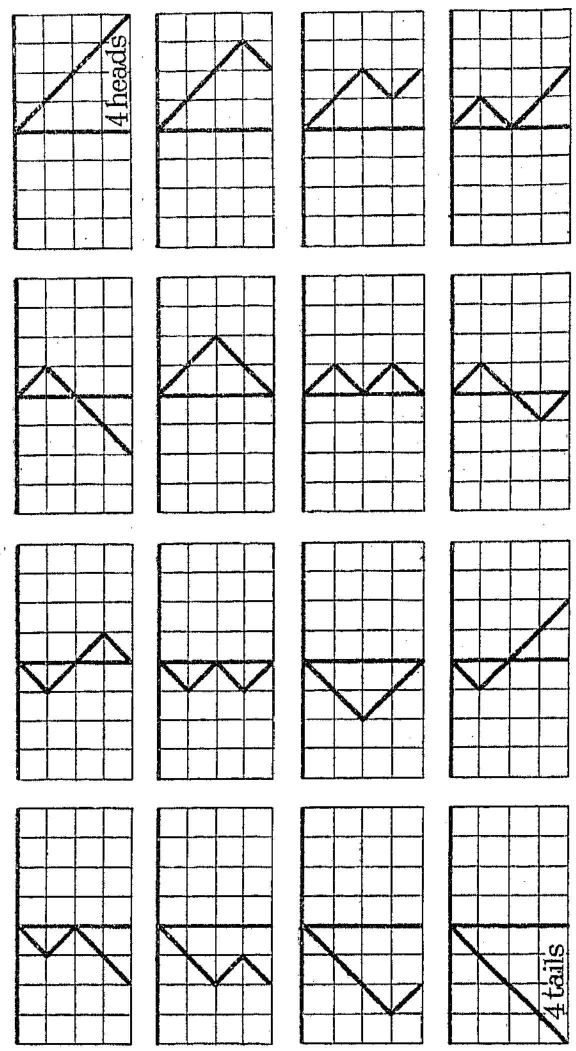

Fig. 4.—Tossing a coin: 4 tosses.

Figs. 3 and 4 show the corresponding results for 3 and 4 tosses respectively, where the total numbers of possible zigzag lines are $2^3 = 8$ and $2^4 = 16$. The probabilities for the various results are:—

3 tosses	3 heads $\frac{1}{8}$	2 heads, 1 tail $\frac{3}{8}$	1 head, 2 tails $\frac{3}{8}$	3 tails $\frac{1}{8}$	
4 tosses	4 heads $\frac{1}{16}$	3 heads, 1 tail $\frac{4}{16}$	2 heads, 2 tails $\frac{6}{16}$	1 head, 3 tails $\frac{4}{16}$	4 tails $\frac{1}{16}$

The numbers which appear in the denominators are evidently the powers of 2, namely 2^n for n tosses. Those in the numerators are called " binomial coefficients "; they can be arranged, following Pascal, in the shape of a triangle, as shown in Table 2, where each number is the sum of the two above it. Table 3 shows a slightly different arrangement of this Pascal triangle. The binomial numbers become rather big in the middle of the array, but are very small at the sides. Clearly, therefore, the probability of getting a series of, say, 1 head and 5 tails, which has the value $1/2^6 = 1/64$, is very small indeed as compared with the probability of getting with the same number of tosses (6) an equal distribution, 3 heads and 3 tails (probability 20/64). This prevalence of the equal distribution becomes

Table 2

1
1 1
1 2 1
1 3 3 1
1 4 6 4 1
1 5 10 10 5 1

more and more marked if the series is taken longer and longer. For 20 tosses one can be practically certain that the distribution having all heads except 1 or 2 will not occur, and for 100 tosses the result will practically always be very close to the equal distribution, 50 heads and 50 tails. If we increase the number of experiments

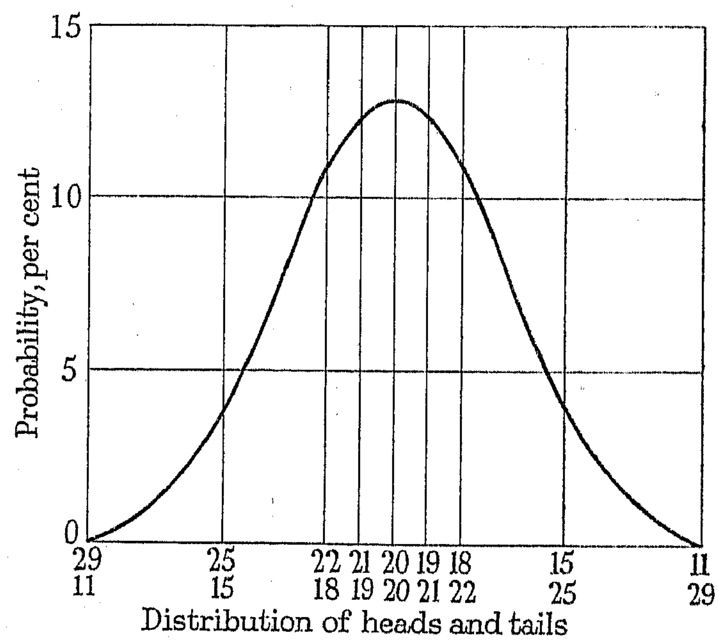

Fig. 5.—Gauss's error curve.

indefinitely the last line of the Pascal triangle becomes longer and longer; we can contract it in such a way that it has always the same length, but then the points in it become denser and denser. If we now plot the probability values as ordinates against the points in this line as abscissae, we get a curve of the shape shown in Fig. 5. It is called the error curve of Gauss, as this great mathematician first discussed it in connection with his theory of the elimination of accidental errors in measurements.

From this curve one can read all the probability results for a very long series of experiments. For instance, if we cut out the middle part of the curve by two symmetrical ordinates in such a way that its area is the same as the total area under the rest of the curve, we see that this middle part is very narrow; it covers only a

Table 3

THE FIRST TWENTY LINES OF THE PASCAL TRIANGLE*

1	1																				2
1	2	1																			4
1	3	3	1																		8
1	4	6	4	1																	16
1	5	10	10	5	1																32
1	6	15	20	15	6	1															64
1	7	21	35	35	21	7	1														128
1	8	28	56	70	56	28	8	1													256
1	9	36	84	126	126	84	36	9	1												512
1	10	45	120	210	252	210	120	45	10	1											1024
1	11	55	165	330	462	462	330	165	55	11	1										2048
1	12	66	220	495	792	924	792	495	220	66	12	1									4096
1	13	78	286	715	1287	1716	1716	1287	715	286	78	13	1								8192
1	14	91	364	1001	2002	3003	3432	3003	2002	1001	364	91	14	1							16384
1	15	105	455	1365	3003	5005	6435	6435	5005	3003	1365	455	105	15	1						32768
1	16	120	560	1820	4368	8008	11440	12870	11440	8008	4368	1820	560	120	16	1					65536
1	17	136	680	2380	6188	12376	19448	24310	24310	19448	12376	6188	2380	680	136	17	1				131072
1	18	153	816	3060	8568	18564	31824	43758	48620	43758	31824	18564	8568	3060	816	153	18	1			262144
1	19	171	969	3876	11628	27132	50388	75582	92378	92378	75582	50388	2 7132	11628	3876	969	171	19	1		524288
1	20	190	1140	4845	15504	38760	77520	125970	167960	148756	167960	125970	77520	38760	15504	4845	1140	190	20	1	1048576

* The column on the right gives the total number of different possibilities for 1, 2, 3, ... 20 tosses.

rather small section of the axis of abscissae. This means that we have the same probability of finding a set of distributions very near the equal distribution (represented by the maximum) as for finding all the other distributions put together.

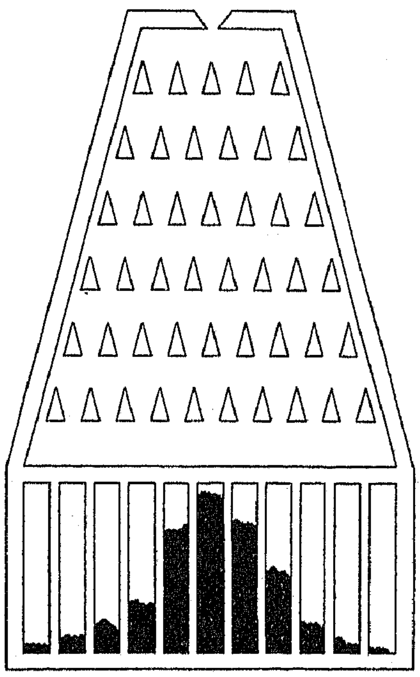

Fig. 6.—Galton's apparatus.

The forming of the Gauss curve as the result of many repeated acts of chance of equal probability can be illustrated by an instrument devised by Galton (see Fig. 6), which is also used with some modification as a game of hazard. Little spheres are set rolling down an inclined plane, starting from a hole in the upper boundary; they meet little obstacles in the form of triangles by which they are deflected with equal probability to the right or to the left. They are collected in a set of cells on the lower boundary, where they form a Gauss curve.

Another application of the same laws is the accidental distribution of a particle in a horizontal box (see Fig. 7). The box is divided into two equal parts by a line; we shake the box and count how often the particle (a little ball) is found in the right or in the left half. Instead of using one particle and repeating the experiment very often, we can just as well take many particles and shake only once. The objection that the positions of the single particles are not quite independent (as each

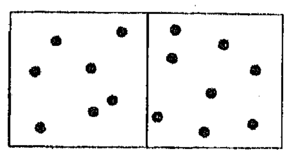

Fig. 7.—Accidental distribution of a number of bodies in a box.

excludes the other from its own volume) is not very serious, for if the diameters are small the interaction is also small, and moreover it has not the tendency to spoil the " accidental " character of the distribution. In this way we can convince ourselves, by means of very few experiments, that the occurrence of nearly equal distributions is overwhelmingly frequent compared with that of essentially unequal ones.

This experiment can be modified by dividing the area of the box not into two equal parts, but into unequal ones. If there is no reason for a particle to prefer any one place, we shall attribute to each part a probability proportional to its area. We have the

simplest case of unequal *a priori* probabilities; this expression means that the probability cannot be reduced to counting of " equal cases," but has to be assumed or derived from other knowledge. It is a natural and obvious generalization of the fundamental definition. If we regard some cases as equally probable because we have no reason to believe that there is a tendency or force in favour of one or the other, we make a hypothesis just as physics is accustomed to do. We try then to justify this assumption by drawing consequences for complicated combinations of cases (as above explained for head and tail) and we compare these with experiments—in this case by actual counting of frequencies of occurrence.

There is no great difference in the case of unequal elementary probabilities; we make a hypothesis, and then try to confirm it by experiment. The choice of this assumption seems to be quite easy and natural in the case of our box: what else could we choose than the area? But it is immediately clear that in doing this we make tacitly another assumption: that the box is kept exactly horizontal. If we had no friction (which is introduced here purposely), then with the least inclination we should find the particle always on the lower rim, and probability would not come into play at all.

This is a very important point. It seems to indicate that some kind of forces must be excluded if chance is to have free play. Forces are causes of motion, but cause and chance are incompatible conceptions. Here we meet a great difficulty: can we ever be sure that there is absolutely no force, e.g. no friction and no inclination of our box? When does the causal process of motion under force cease, and yield to the accidental distribution? It is clear that there can be no sudden jump between these two conditions. There must be a domain of transition between causal and accidental processes, where a kind of hybrid law will hold. This domain is evidently that of very small forces. If, however, very small forces act on very small particles the effect will be considerable, the domain of hybrid laws extended. This indicates that the most interesting revelations about the reign of chance must be expected from the investigation of the smallest particles—atoms, molecules, electrons. And this is really the case; atomic physics has contributed the most fundamental laws to the theory of chance and probability, which the observation of our common world could never have revealed.

We shall return to this question later; but let us first glance at the practical use of the simple theory of probability (as explained above) in everyday life and in those sciences which do not resolve their objects into minute particles.

PROBABILITY IN LIFE AND SCIENCE

The most direct applications of the laws of probability are to all kinds of games and gambling; we have to do with obvious generalizations of the facts which we explained with the help of the example of the head-tail game. In card games the elementary probability of one player getting any of the cards is considered to be the same. From this, one can derive the probability of getting a definite hand, or a hand containing definite features, e.g. the 4 aces. Fig. 8 shows the distribution of aces in bridge as predicted by the theory of probability, and as observed in an actual series of 840 dealings. The probability of getting 0, 1, 2, 3, or 4 aces in one hand is represented by sectors of a circle. The agreement between theory and observation is astonishingly good.

There are many opportunities of applying the laws of probability in problems of social and economic life; but here it is hardly possible to establish elementary probabilities by simple reasoning about equally probable cases or by other kinds of *a priori* assumptions. One has to go the opposite way, to count great numbers of cases, to establish statistical tables, and to derive from them elementary laws of distribution. This science of statistics has been developed very far; it constitutes an independent and important branch of applied mathematics. The insurance companies, for example, employ in their offices experts in statistics who have to work out the tables on which the prosperity of the company and the reliability of the service depend.

There is no doubt that such statistical predictions are confirmed by experience. Where deviations occur, due, for instance, to an " abnormal " increase of the death rate in a certain region, they can be traced to a physical cause such as an epidemic disease; the absence of cause is always characterized by the validity of the statistical predictions.

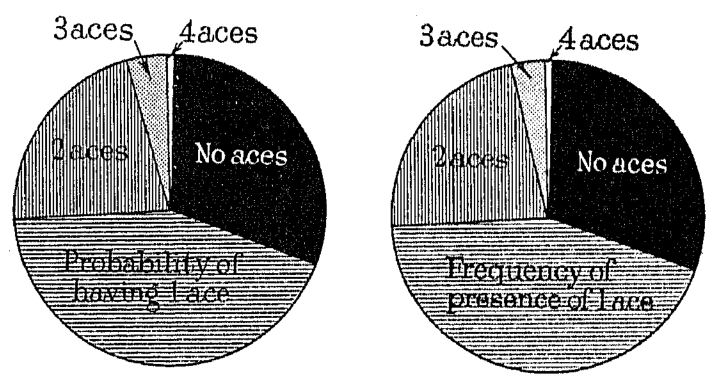

Fig. 8.—Distribution of aces in a game of bridge.

There is one application of the theory of probability which concerns all sciences depending on exact measurements. It is the theory of errors of observation, which, as has already been mentioned, was initiated by Gauss. When all predictable errors in a measurement have been taken into account there remain always " accidental " deviations: even the most expert observer does not get the same results if he takes a reading of an instrument twice under apparently the same conditions. It is obvious that one has to take the mean value of the observations. Generally one is not interested in the observed values themselves, but in some physical constants which are related to the observations by known laws. The problem is to determine the most probable values of these constants which are consistent with the measurements. The solution of this problem—Gauss's " method of least squares "—is of the greatest importance in relation to all measuring processes.

Among the special sciences in which probability plays a role is biology, where it is used to predict the fundamental facts of genetics. If there are two pure species of a plant or animal, differing by one observable property (e.g. peas, one species having red and the other white blossoms), the offspring can be of three kinds—either similar to one or

the other of the parents (red or white), or a mixture (flowers with red and white petals). Mendel's experiments have shown that numerically these types occur in the ratio 1 : 1 : 2, exactly as with a combined probability of two equally likely alternatives, such as the head-tail game. This result has been confirmed in many cases, and though it is frequently complicated by secondary phenomena it has become the basis of all genetical research. The reproduction of life is a combinatoric process; each property corresponds to some element in the generative cells, called genes, which combine by chance.

Fig. 12.—Extra-galaxic nebula.

Modern biology has been able to discover that the carriers of these genes are the chromosomes of the cellular nucleus, and to confirm by direct microscopical observation the results derived from counting the offspring.

Another science which uses statistical methods is astronomy. Figs. 9 and 10 (see Plate 1, facing page 808), showing respectively a nebula and a star cluster, illustrate the enormous number of stars made visible by the gigantic modern telescopes. It would be a hopeless task to study single stars, but one can get some information from mass observation, by counting and then applying the laws of statistics. I will give only one example of this method. The Milky Way, or Galaxy, spreads like a glowing ribbon over the sky. What does this astonishing arrangement of the stars really mean? The statistical method has given a very satisfying explanation. Our sun belongs to a system of some hundred million stars which form an enormous lens-shaped structure. The sun, with the planets, is located somewhere in the interior, not far from the centre; therefore we see many stars in the direction of the middle plane, but few normal to this direction, and we get the impression of the ribbon-shaped Milky Way. The dark line in the equatorial plane in Fig. 11 (Plate 2) is assumed to represent the absorption of the light by cosmic dust distributed between the stars. The length of the long diameter of this system is about 100 000 light years. You will get an idea of this enormous distance if you remember that light travels 186 000 miles a second; it takes 8 minutes for light to travel from the sun to the earth, and about $5\frac{1}{2}$ hours to the most distant planet, the recently-discovered Pluto, but 100 000 years to travel the length of the Galaxy!

Fig. 12 shows a real object in the sky, photographed with help of one of the most powerful American telescopes. We observe immediately the striking similarity to Fig. 11—even to the dark line in the middle. We see here a nebula or family of stars similar to our own Galaxy, of similar dimensions, in a distance which is about 100 times larger than the diameter. Enormous numbers of such nebulae have been discovered, and statistical investigations have shown that they fill the universe more or less uniformly as far as our biggest telescope (the 100-in. mirror on Mount Wilson) can penetrate.

PROBABILITY IN CLASSICAL PHYSICS

The infiltration of physics with statistical methods went parallel with the development of atomic theory; for the atoms are far too small and too numerous to permit individual treatment.

The first success of a statistical interpretation of physical laws was the kinetic theory of gases. A gas was supposed to consist of innumerable equal molecules flying like a swarm of mosquitoes, bumping against one another and against the walls of the vessel. It was easy to explain the pressure of the gas as the average result of all the collisions of the molecules with the wall, and in this way there was derived the well-known law of Boyle and Mariotte, that the pressure varies inversely as the volume for constant temperature. The temperature itself could be interpreted as meaning the average kinetic energy of the molecules. Many other properties of the gas could be explained in a similar way.

The assumption underlying the kinetic theory of gases can be verified by applying the laws of probability in a rather more refined way. The simplest problem is the distribution of a gas over different parts of a vessel. Imagine a plane dividing the vessel into two equal parts. We have then apparently a similar case to that illustrated in Fig. 7. Assuming that there is no force acting on the molecules we can infer, just as before, that there is an overwhelming probability of a nearly equal distribution of the particles in the two parts; this probability will be all the more overwhelming seeing that the numbers of molecules are so incredibly great. There are about 10^{20} molecules per cubic centimetre, and the combinatory numbers such as $n!$, or the binomial coefficients, are

enormous. Therefore the probability predictions should be more certain than for any problem of everyday life, as indeed they are! For example, have you ever reflected that it is possible for a man to be suffocated by chance? I mean, if the molecules are distributed at random, it may occur by unhappy chance that there is no molecule in the neighbourhood of my mouth for a few minutes, and I shall then have no air to breathe. Well, I am not afraid that my career may end in that way.

But there is a serious objection: what of the effect of gravity? Why do not the molecules fall, and accumulate at the bottom of the vessel? The problem is not in fact so simple as is represented above, as we are here in the domain of hybrid laws—partly statistical and partly mechanical. To understand these mixed laws we must remember that we cannot predict the motion of a system from the laws of mechanics unless we know its initial state. The application of mechanics to the problem of the firing of a gun gives all possible orbits of the shell, but which orbit it will describe in a given case is decided by the initial position, elevation, and velocity. If we have to do with a system of many particles, like the molecules of a gas, the total of these initial conditions is enormously large and just as important as the laws of mechanics, which say not much more than that the orbits are nearly straight lines between two encounters. Now, it is clear that we can never know the initial conditions—the position, direction, and velocity of every single molecule at any given instant. We have to apply the laws of probability to these initial conditions, and it seems as if these have nothing to do with forces. The forces should influence only the motion after the start. But this is, in fact, erroneous. It has been found that the forces, or, more exactly, the potential energy of the forces, has a direct influence on the *a priori* probability of the initial state. I shall try to explain this for the example of the density of a gas.

If we compare two volumes having the same shape which are situated at the same level we have, of course, the old case of equal probability; the two volumes will contain very nearly equal numbers of particles. But if these volume-elements are situated one above the other, so that work is needed to lift a particle from the lower to the upper, then the probabilities of finding a given particle are not equal. The *a priori* probability of finding a particle decreases with the height—it is an exponential function of the potential energy (weight × height). This decrease in density is very small in a vessel such as is used in laboratory work. It is more obvious in the free atmosphere: it is a well-known fact that the barometric pressure decreases with the altitude. (The observed law of this decrease is not exactly the same as the theoretical one, since the latter holds only for equilibrium at constant temperature whereas the free atmosphere is not isothermal and is disturbed by wind, clouds, dust, and rain.)

The general law of statistical mechanics determines the *a priori* probability of finding a particle in a given region of space and momentum (mass × velocity) as an exponential function of the total energy, which depends on the position and the momentum, and it states that if the particles could be counted in any definite instance the result would conform to this law. This statement contains, incidentally, a formidable mathematical problem. If we have started the system from a given situation, it will certainly follow the laws of dynamics. But we could with equal right regard any subsequent instant as the "initial" one: why are we allowed to apply again the laws of probability? Is it not possible that, starting from the initial state conforming to the statistical law assumed, we might find, as a consequence of the dynamical laws, a quite different distribution at a later instant? This problem has puzzled the mathematicians for many years. As a solution could not be found, the physicists introduced under the name "quasi-ergodic hypothesis" the required result as if it were a physical assumption, and not a logical consequence, or a logical contradiction, of other assumptions made. This unsatisfactory situation was eventually disposed of when the American mathematician Birkhoff gave a rigorous proof of the theorem.

The laws of statistical mechanics have been confirmed by many experiments in which quantities predicted by the theory are measured. But more direct evidence of the truth of the laws is available. We have spoken about the distribution of the molecules in a gas under the action of gravity. Can we not adjust the conditions in such a way as to make visible the operation of the distribution law in the laboratory? If we could increase the size of the particles, the potential energy, which is proportional to the weight, would also increase, and therefore the gradient of the density. This is clear; for if the particles were of the size of the balls used in our former experiment the whole "atmosphere" would collapse, and all the balls would cover the bottom. Between this limiting case of dominant gravitational force—the big balls—and the other limiting case of dominant chance distribution—the gas molecules—there must exist all kinds of intermediate cases, particles of medium size which form atmospheres of corresponding gradient. One can choose the size of the particles in such a way that they are visible, perhaps with the help of a microscope, but small enough to form an easily observable gradient of density. These particles—dust or smoke in the air, dye stuff in ink, or other colloidal solutions—are of course not suspended in a vacuum but surrounded by the molecules of the gas or the liquid. But this does not matter; the same distribution law holds for all kinds of particles, irrespective of their surroundings, as long as they are sufficiently diluted. The visible particles dance on the molecules of air or liquid. Fig. 13 (Plate 2) shows results obtained by the French physicist Perrin which inindicate the decrease of density with height. The importance of this kind of experiment consists in the possibility of determining the number of molecules in a given weight of the surrounding medium, by counting the visible particles in different layers.

Observation of such particles in suspension has provided another direct proof of the kinetic theory and the statistical character of the laws associated with it. If the particles are very small, so that a strong microscope or even an ultra-microscope has to be used, one sees that they are not at rest but are performing a very irregular zigzag motion (see Fig. 14). This phenomenon, called the Brownian movement, is very impressive and provides the most direct evidence of molecular motion. Its explanation is obvious: if the suspended particle is very small, the impacts suffered from the surrounding mole-

Plate 1

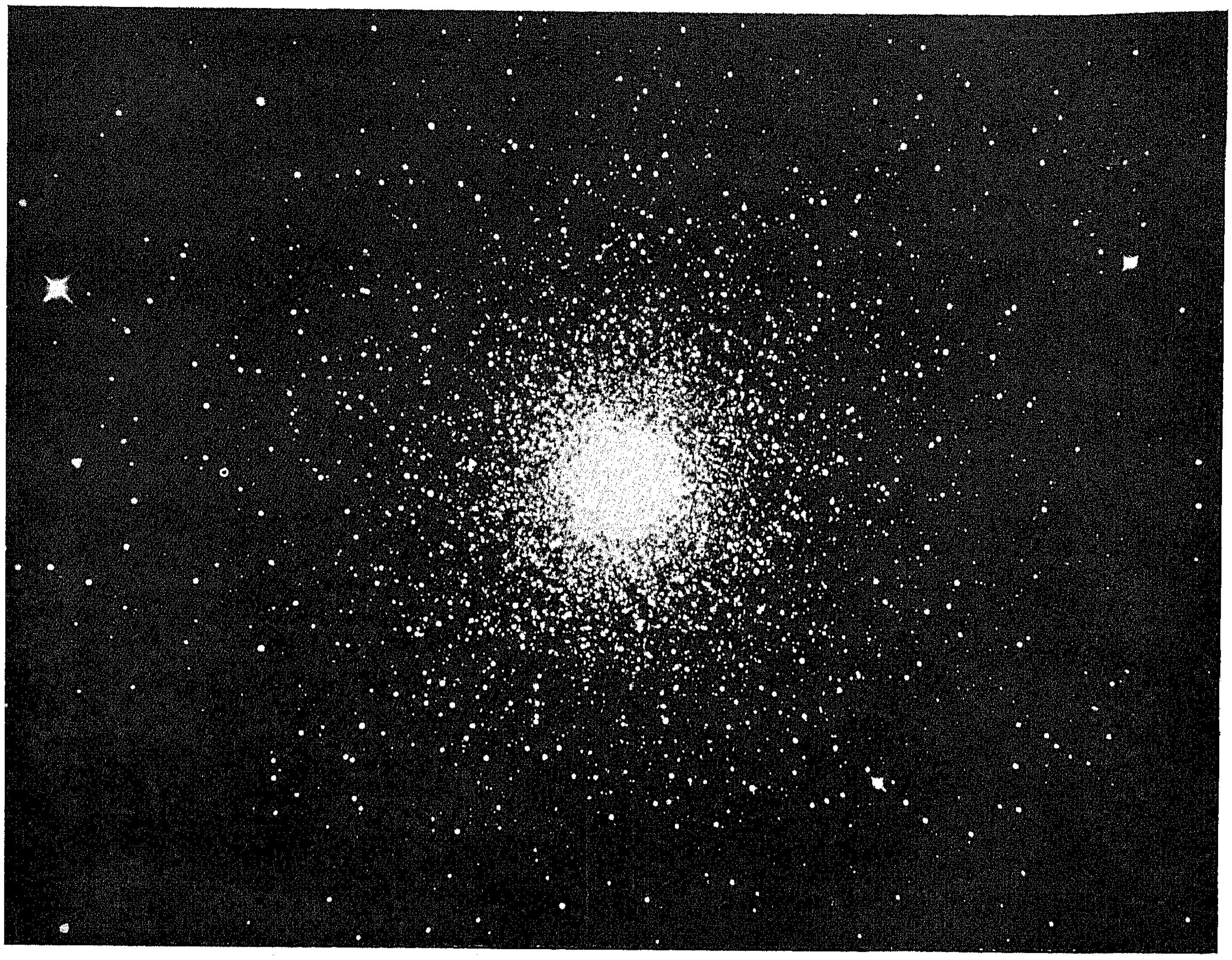

Fig. 10.—Star cluster.

Fig. 9.—Nebula.

Plate 2

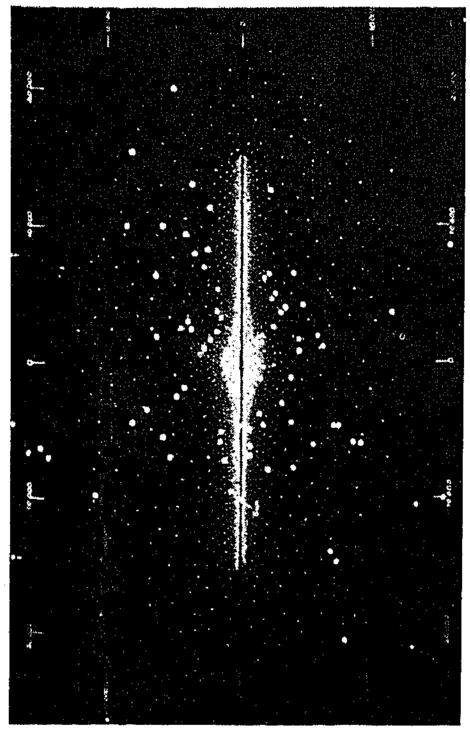

Fig. 11.—The Milky Way.

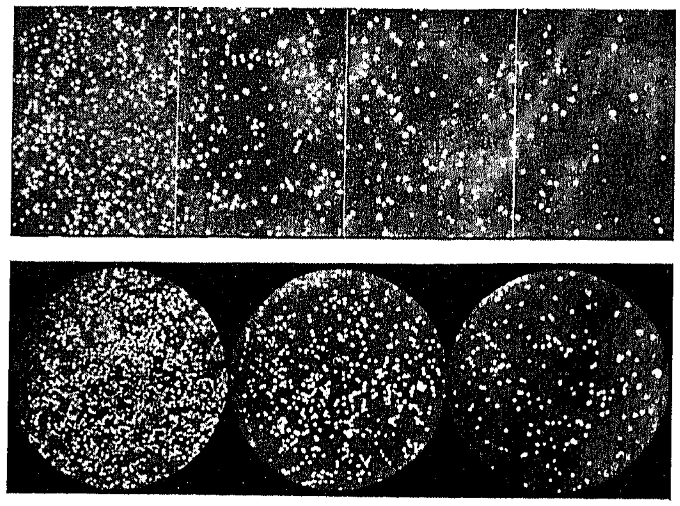

Fig. 13.—Suspension of colloidal particles.

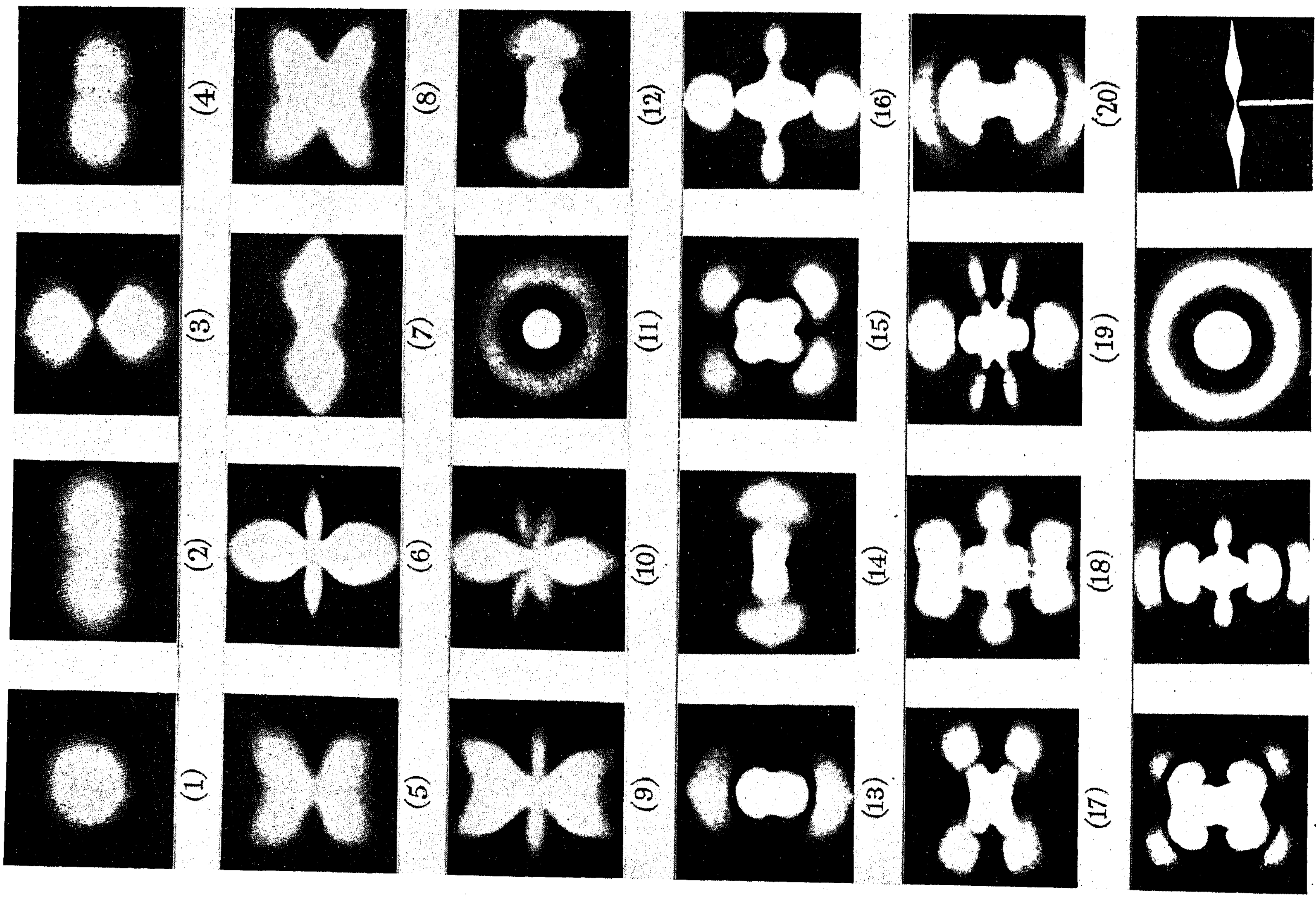

Fig. 19.—Electron clouds as given by wave mechanics, for different stationary states.

cules do not exactly cancel one another out. In other words, if the particle becomes progressively smaller it must approach the behaviour of a single molecule and take part in its heat motion. All bodies, even the heavy objects of our daily life, take part in this ceaseless movement, which is only unobservable because of their great weight. For according to the statistical theory the average kinetic energy of a particle for a given direction of motion is always the same, whatever its size and mass; since the kinetic energy is equal to half the mass times the square of the velocity, the latter becomes smaller and smaller with increasing mass for a given energy-content.

The blue colour of the sky (see Fig. 15) is a phenomenon which could not be explained until the kinetic theory was

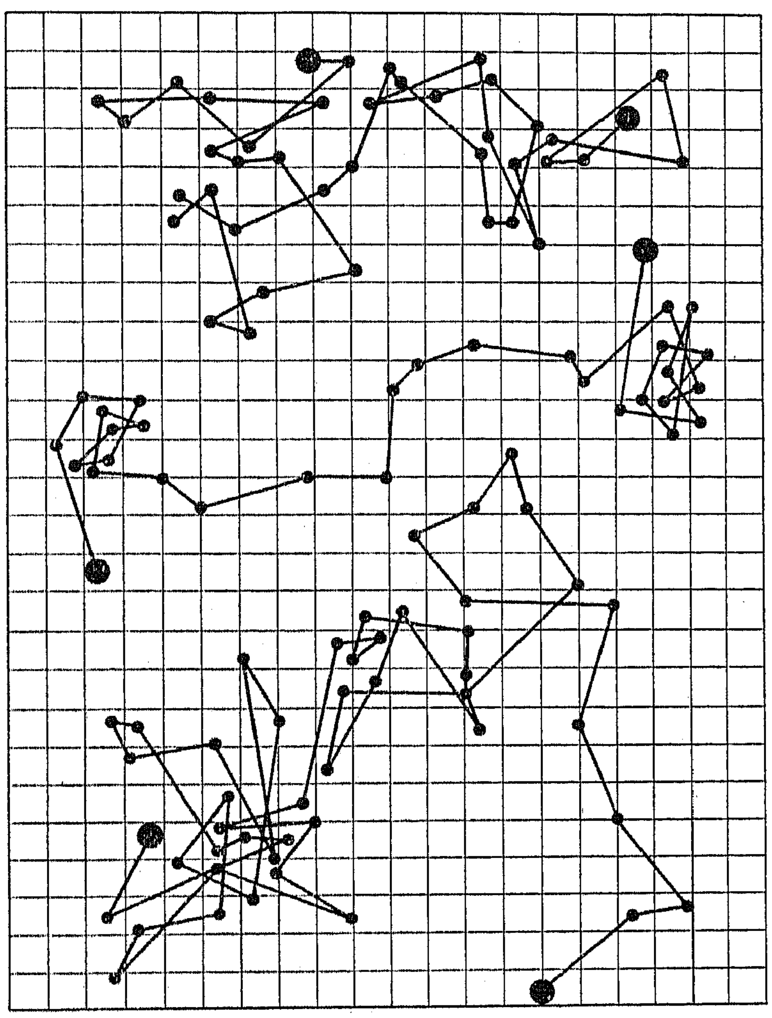

Fig. 14.—Brownian motion.

developed. The explanation was given first by the late Lord Rayleigh, who combined in a remarkable way a thorough knowledge of optics with a deep understanding of the laws of statistics. The optical question is this: if we look at the sky in a direction normal or even opposite to the sun's position no direct rays from the sun reach our eyes; the light which we see must be reflected or scattered from the air. Now if there are particles swimming in the air, e.g. dust or droplets of fog, the origin of the scattered light is evident. But we see the blue of the sky also when we are on high mountains or flying in aeroplanes, at altitudes where there are no particles of matter in suspension, and there the blue colour is most beautifully developed; it becomes purer and darker with increasing altitude. Laboratory experiments have confirmed that absolutely pure, dust-free air scatters the light of a passing beam. Each molecule is, indeed, an obstacle for the light wave and scatters it in the form of a spherical wavelet, just as a pole in water is surrounded by circular wavelets. But if the air molecules are uniformly distributed all these wavelets will destroy one another by

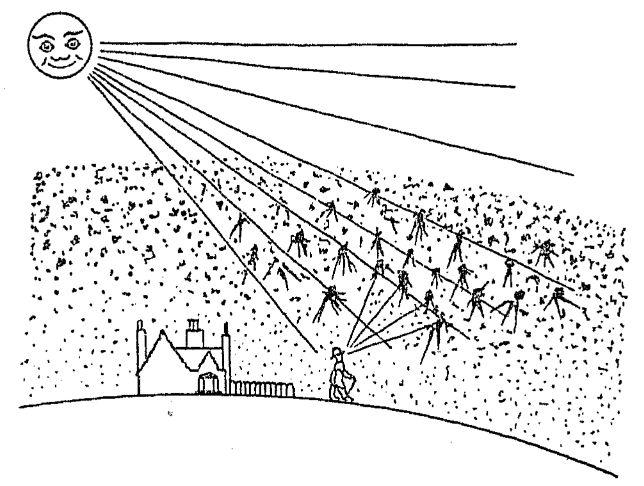

Fig. 15.—Scattering of sunlight by the earth's atmosphere.

interference. The scattering can be observed only if there are fluctuations of density; these act as obstacles to the incident wave just as if they were particles of other material. The blue colour of the scattered light is now easily understood. For blue light is of shorter wavelength than yellow or red light, the ratio of the wavelengths at the red and the violet end of the spectrum being about 2 : 1 (see Fig. 16). Each wave will be deflected mainly by obstacles of a diameter nearly equal to the wavelength. It is clear that small fluctuations of density are much more frequent than larger ones, and therefore short waves are scattered more than long ones. This explains at the same time the red colour of the sun at sunrise and sunset; when the sun is low down the light has to travel a long way through the atmosphere to reach our eyes. On the way it loses most of its blue components, and therefore appears red.

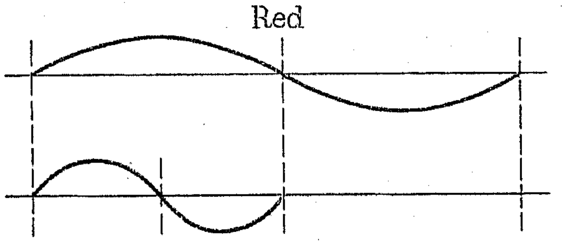

Fig. 16.—Wavelengths of red and violet light.

If we want to measure small effects we have to use very sensitive instruments—very light pointers, needles, or mirrors, suspended by extremely thin quartz fibres. But the thermal agitation of the moving parts sets a natural limit to the improvement thus obtainable, and our best instruments have already reached this limit. It cannot be avoided by putting the needle in a vacuum, for the suspending fibre is also subject to thermal agitation. A similar effect is observed in relation to electric currents, which can be kept constant only to the natural limit where the thermal fluctuations become observable. The fact that these electrical fluctuations exist shows

clearly that electricity has an atomistic structure; it is strong evidence in favour of the electronic theory, of which I shall speak later.

Before doing so let me refer briefly to other applications of statistical mechanics. There are, for example, the phenomena connected with electrical discharges in gases, where we have to deal with the statistics of charged particles; the study of these effects is complicated but highly developed, and has led to the construction of rectifying and amplifying valves, X-ray tubes, the coloured lighting used for advertising, and so on. There is also a fully developed statistical theory of the solid state, and the beginnings of a statistical theory of liquids. Solids are either single crystals, or accumulations of many little crystals, or glasses, which can be regarded as liquids of a very high viscosity. The atoms of a crystal have definite equilibrium positions, forming a regular pattern or "lattice." They can be studied with the help of X-rays, and are well known to-day. A mineral as found in nature, or a piece of metal as used in industry, is a random collection of little crystals of all shapes and sizes. The properties of such a material depend, therefore, to a high degree on accidental features and can be treated only with the help of probability considerations. The study of real solids by this method is only just beginning; for a long time interest was concentrated on the single crystal, and even here chance plays an important role, e.g. in the alloys. These may be geometrically nearly ideal regular lattices but in such a way that the lattice points are occupied by two (or more) kinds of atoms, say copper and zinc, in a more or less random distribution. The statistical treatment of these "solid solutions" has recently been much developed by a new method invented by W. L. Bragg, which he calls the theory of order and disorder. Let us now consider the simplest possible case, an ideal lattice consisting of only one kind of atom, e.g. a cubic copper crystal. In this case the thermal agitation consists of vibrations of the atoms about their equilibrium positions. The simplest assumption is that each atom vibrates about its equilibrium position independently of the others. We have then to treat the statistical behaviour of a set of oscillations all of which are of the same frequency, and we find that the average energy of such a system is just twice the kinetic energy (the potential energy contributing the same amount); and, as the kinetic energy determines the temperature, a solid should always have double the amount of energy that a gas of the same number of atoms has. This rule, known as the law of Dulong and Petit, is in excellent agreement with experiment for most solid substances at room temperature. Some substances do not obey the law, and it has been discovered that deviations occur for all substances if the temperature is lowered. We shall return presently to this important point, one of the roots of the revolutionary idea of the quantum theory which has transformed physics.

We have first to correct our model consisting of independent equal vibrators, which is evidently very rough. For all the atoms of a crystal are bound together: we cannot set up a vibration of one atom without disturbing the equilibrium of its neighbours. We have to do with a coupled system having a most complicated structure; nevertheless, it has been possible to treat it rigorously, with the simple result that compared with the deductions made from the original model nothing essential is altered. We can still regard the crystal as a system of independent oscillators, but not all of these have the same frequency; there is a frequency spectrum covering a wide range. Each oscillator is not a real, single vibrating particle, but a more abstract thing. You know that a violin string has a set of elementary vibrations which give pure tones: a fundamental tone in which the string vibrates as a whole, and overtones with frequencies 2, 3, 4, etc., times as high, where the string exhibits 1, 2, 3, etc., nodes (see Fig. 17). Any vibration of the string can be regarded as being built up from a number of these elementary or "normal" vibrations. Similar remarks apply to a three-dimensional elastic substance: any arbitrary state of vibration may be regarded as the resultant of a great number of "normal" vibrations, whose amplitudes are independent and can be subjected to mathematical treatment. This complication is purely arithmetical and in no way affects the derivation of the law of Dulong and Petit. It is, however, of importance from the point of view of the deviations mentioned above, which occur at low temperatures and led to the quantum theory.

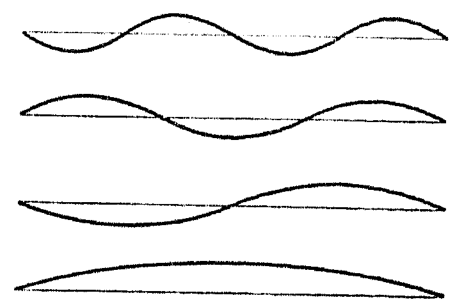

Fig. 17.—The fundamental vibration and overtones of a string.

This theory had its origin in the problem of the heat radiated from hot bodies. It is evident that the random motion of the atoms of a heated body will induce a random distribution of the amplitudes of the electromagnetic waves which carry away a part of the energy as radiant heat. By observing the spectral distribution of the heat radiation one can study the behaviour of atomic oscillators. It has been found that they do not agree at all with the laws predicted by statistical mechanics. It was Max Planck who, in 1900, suggested that these deviations could be explained on the assumption that the energy of an oscillator cannot have any value, but only integral multiples of a certain elementary "energy quantum," and that this quantum ϵ must be proportional to the frequency ν of the oscillator. Thus $\epsilon = h\nu$, where h is Planck's constant. In 1905 Einstein showed that the same asumption was able to account for the deviations of the specific heats of solids at low temperatures from the law of Dulong and Petit.

PROBABILITY IN THE QUANTUM THEORY

The quantum theory developed in well-marked stages. The first was that in which the fundamental ideas were introduced and applied to the thermic properties of radiation and solids. Then came another discovery, by Einstein, connecting the quantum idea with the photoelectric effect, in which electrons are expelled from

certain metals by a beam of light or of X-rays. He showed that the observed properties of this effect are direct evidence of the quantum structure of energy and also of Planck's law, $\epsilon = h\nu$; for the energy of the electrons driven out by the light does not depend on the intensity of the light wave, but is always the same for the same frequency of the light, as if this were composed of " light quanta " or " photons " of magnitude $\epsilon = h\nu$. We have here a revival of Newton's corpuscular theory of light, which had been abandoned in favour of the wave theory of Huygens about 100 years previously. Einstein was aware, of course, of the extreme difficulty of reconciling the corpuscular theory with the well-established facts of interference and diffraction, which prove the wave character of light. The only solution of this riddle is the assumption that light consists of particles and waves at the same time, the particles carrying energy and momentum, the waves directing their motion. For at any point where the wave theory predicts a strong intensity of vibration, experiment shows the appearance of a great number of photons. Acceptance of this suggestion implies the decisive step of attributing physical reality to the idea of probability; and we shall see immediately that this hypothesis of " probability waves " has a much wider field of application.

The third period of quantum theory was due to Niels Bohr. In the first decade of this century fundamental discoveries were made: X-rays by Röntgen, radioactivity by Becquerel and the Curies, the laws of radioactive integration and the electronic structure of atoms by Rutherford and his collaborators. Bohr successfully applied the quantum theory to the motion of the electrons in the atom. He introduced the idea of stationary states of these electrons, and explained the emission of line spectra by an ingenious application of the quantum law to the transitions between these states. He developed also a fairly complete picture of the stationary orbits of the electrons (see Fig. 18), and gave a general qualitative explanation of the periodic system of the elements. But this theory was a rather crude adaptation of classical mechanics to the quantum postulate, and was quite inadequate for quantitative prediction.

The new mechanics was developed in 1925, as the result of independent investigations by several workers. One of these was initiated at my former university, Göttingen, on the basis of an idea due to Heisenberg, and was worked out in co-operation with Jordan and myself; another was started in Paris by de Broglie, and developed by Schrödinger in Zurich; the third was that of Dirac at Cambridge. It is formally a generalization of the classical theory, but is intrinsically different in its philosophical aspects. For it means the definite abandonment of the causal laws of classical mechanics in favour of an indeterministic theory which includes the idea of chance and probability in the ultimate laws. The sharp stationary states of the electrons in the atoms, as illustrated in Fig. 18, are replaced by the more nebulous systems shown in Fig. 19 (Plate 2). There are still quantum states with definite energies as in Bohr's theory, but instead of being a definite orbit each of these is a kind of cloud the shape of which has some similarity to the orbits of the older theory. The density of the cloud determines the probability of finding an electron at a given place.

This statistical interpretation which I have proposed suggests itself if we assume the electrons to move freely, as in a cathode ray, and not to be bound to atomic nuclei. The strange prediction of de Broglie, that such a ray should behave as a wave and show interference fringes like those produced by a beam of light under similar conditions, was fully confirmed by experiments, first performed by Davison and Germer in America and by G. P. Thomson in this country. The cathode ray exhibits the same dual behaviour as does light: from the energy point of view it behaves as a rain of particles, but it spreads according to the laws of wave propagation. The only possible interpretation is also the same as in the case of light, namely a wave of probability determining the appearance of particles.

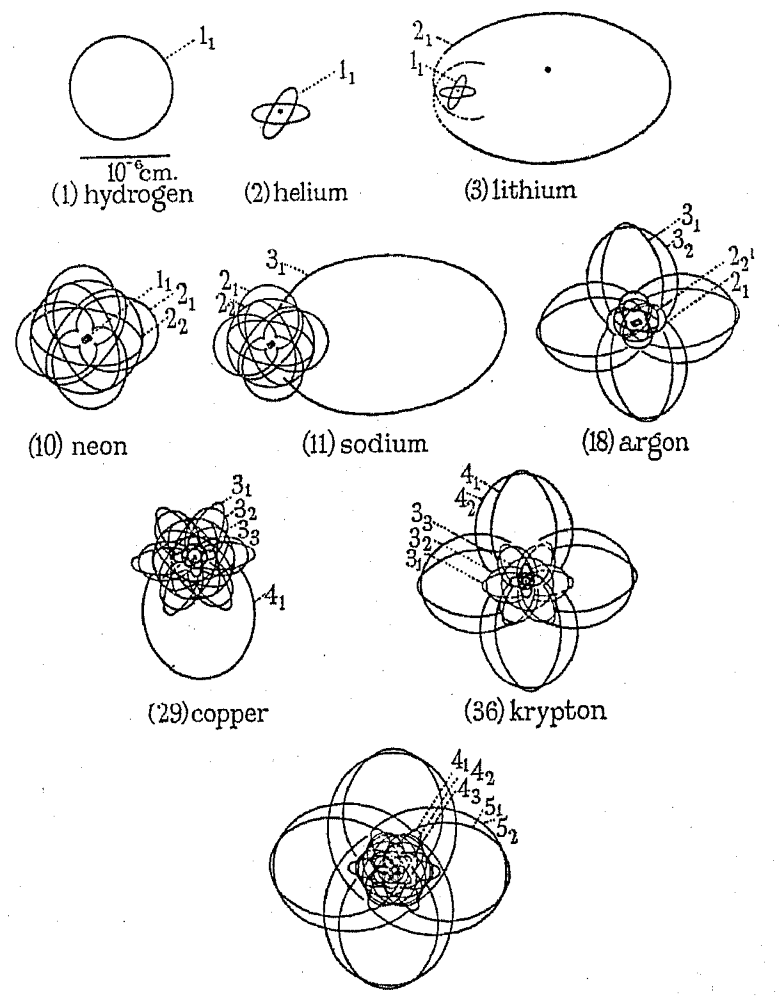

Fig. 18.—Stationary orbits of the electrons in Bohr atoms.

Experiment has amply confirmed this theory. It has been supported not only by the direct observation of interference fringes due to cathode rays, beams of helium atoms, and beams of hydrogen molecules, but also by the scattering effects which can be observed when a beam of particles collides with matter. In this case the mutual force between the atoms of the bombarded substance and the incident particles can be regarded as producing an alteration of the velocity of the probability wave of the beam, or, in other words, a change of the index of refraction of the wave; this acts like an obstacle on the wave which is scattered, just in the same way as the light from the sky is affected by the accidental density fluctuations of the air molecules. The strengths of the scattered wave in different directions determine the number of

particles flying in these directions. Many observations which could not be explained by the application of classical mechanics are fully accounted for on the theory of probability waves.

This simple picture must be drastically modified when we have to deal with particles which do not move independently but act on one another. I cannot explain these complications, but I wish to stress the idea that in modern wave-mechanics probability has become a physical reality.

This idea is no more mysterious than other physical concepts. For example, is it not a miracle that, as Galileo and Newton stated, a body is deflected by another one in such a way that its acceleration is directed towards the other body and has a value proportional to the inverse square of the distance? Perhaps when we learned this law at school we were really convinced that it was an advance compared with the ancient theory which connected force with velocity. But the chief point is that we became accustomed to this law, and took it for granted. We have seen that pre-quantum statistical mechanics was compelled to ascribe to force quite a new function, namely the determination of *a priori* probabilities for the distribution of many particles (which is an exponential function of the potential energy of the force). Instead of saying that a space free of force is one in which a particle moves in a straight line with constant velocity, we could define such a space by saying that the probability of finding a particle in a given instant is the same for any two equal parts of the space. And the deviations from this state of constant density of probability could be regarded as a definition of force. (The only difficulty would arise from the fact that the idea of temperature, or the mean kinetic energy of a set of particles, enters into this definition.) Modern wave mechanics proceeds exactly along this line, starting from an *a priori* probability which is the intensity of a wave (the square of its amplitude) and depends on the forces. The probability has thus become a physical entity, with some kind of reality. If you ask me what I mean by physical reality, I am inclined to reply, that it is something we are accustomed to, something the mystery of which we have forgotten. For example, in the electromagnetic theory the conception of a field has physical reality; but 50 years ago this was not the case. The term " field " was then nothing more than an abstraction for describing the distribution of forces; but these forces were always thought of as attacking charged bodies or particles. It meant a strong mental effort for the physicists of the generation preceding ours to get rid of this restriction, to consider with Faraday, Maxwell, and Hertz that a field may exist even if there is nothing for it to act on, to ascribe to it energy and momentum, and to understand how these are carried along by the field waves. Another mental effort was needed when Einstein's theory of relativity deprived us of the possibility of imagining the ether, the carrier of the electromagnetic waves, as a substance in the common sense of the word. We now have to make a further mental effort in order to regard probability as a physical reality satisfying wave equations just as does the electromagnetic field.

In wave mechanics the idea of probability is an essential part of the mechanical laws governing even a single particle. If we have to do with many identical particles there appear new features (even if all interacting forces are neglected) which lead to a fundamental modification of the statistical laws of gases. If the motion of a particle is described by a wave, the particle loses its individuality. Two equal particles cannot be distinguished or numbered. Thus, returning to the head-tail game discussed in Figs. 2, 3, and 4, i.e. the distribution of 2 particles in 2 identical cells, we have the three cases represented in Fig. 20.

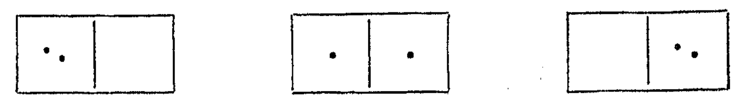

Fig. 20

But to the middle one we attributed twice the probability associated with the other two, since, if the particles were distinguishable, it could be realized in the two ways shown in Fig. 21.

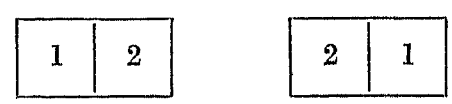

Fig. 21

This doubling, or multiplying, of the cases near the condition of equal distribution is characteristic of the classical statistics. In wave mechanics we have nothing of this kind. The question which particle resides in a given cell is quite meaningless. This assumption leads to a new kind of statistics, called Bose–Einstein statistics.

A volume filled with electromagnetic radiation can just as well be regarded as filled with a gas consisting of photons; as these are indistinguishable from each other they do not obey the common gas laws, but the modified Bose–Einstein laws, and these lead immediately to the law of Planck which holds good for the radiation.

There is yet another deviation from classical laws, which has its root in a law observed by Pauli when he analysed the spectra of atoms, namely that if an electron is in a certain quantum state, corresponding to a certain wave, no other electron can be in the same state. (The same holds also for other elementary particles—protons and neutrons.) Each quantum state can be either occupied or not occupied; double occupation is ruled out. This leads to another kind of statistics, called Fermi–Dirac statistics, which deviates widely from the classical type and has become very important since Sommerfeld remarked that it ought to apply to the free electrons in metals.

The high electrical conductivity of metals can be explained by assuming the existence of unattached electrons which can move freely between the atoms; these electrons form a kind of gas and can be treated by the methods of the kinetic theory. But the application of the classical laws leads to serious difficulties. Each of the electrons should have the same mean energy as any free particle; but then the heat content of the metal would be much higher than that of a non-conductive substance with the same number of atoms, which is not the case. This and other difficulties disappear if the new quantum

statistics is used. On this basis a very elaborate theory of the metals and alloys has been built up which has explained and predicted a great number of facts.

Remembering that conducting metals are the chief material of the electrical engineer, we may return from the lofty heights of physical theory to the practical problem with which you are concerned. I think that an engineer should be disinclined to accept accident as a principle of nature—the word has an awkward double meaning. But as we physicists are not fatalists we continue to make predictions. We have learned that these are never absolutely reliable, and have studied their deviations from the truth. These are negligibly small in the domain of the engineer. But they exist, and their study has led to a deeper understanding of the fundamental laws of nature.

Some of the illustrations and tables in the Lecture are taken from the book by Marcel Bol, "La Chance et les Jeux de Hasard" (Larousse, Paris).

DISCUSSION ON "LAYOUT AND RUPTURING CAPACITY OF PROTECTIVE DEVICES IN MOTOR CIRCUITS"*

EAST MIDLAND SUB-CENTRE, AT LOUGHBOROUGH, 22ND MARCH, 1938

Mr. B. C. Bayley: I am in agreement with the author in his desire to limit short-circuit currents on low-voltage busbars; for industrial consumers taking a public supply are faced with serious problems in regard to rupturing capacity in low-voltage circuits, owing to the enormous increase and concentration of power over the last decade. The replacement of existing low-voltage switchgear, often at heavy cost, may be the only solution, since increasing the supply reactance only leads to bad voltage regulation, and I think that a limit should be laid down for the possible maximum short-circuit value at the supply terminals. It is not as easy for an industrial engineer as for a supply engineer to distribute at high voltage, because he is unable in most cases to obtain space for his transformers and switchgear, in order to step down in close proximity to a section of the load. Most industrial engineers find that executives are loath to allot valuable productive floor space to electrical plant.

It is often almost impossible in laying out an industrial installation of motors to forecast the load over a period of years and to limit it to 1 000 kVA at any one transformer station. As the years go by one gets increased demands for motors of small horse-power (say, not more than 40 h.p.), and often this problem has to be faced on an existing 400-volt installation.

I am inclined to think that the author has set the limit for transformer capacity too low, for it would be very expensive to adopt his suggestion of limiting the capacity to 1 000 kVA. We have recently installed an industrial plant having a transformer of 2 000 kVA capacity which at 400 volts necessitates the use of a 3 000-ampere low-voltage circuit-breaker, with external reactances which limit the short-circuit value on the l.t. distribution board to 15 000 kVA; and we hope we have secured a reasonably safe condition without seriously impairing our voltage regulation.

In all new work we have of recent years installed high-rupturing-capacity fuses on our main sub-circuits. We have not had them in use long enough, however, to say much about their performance. It is essential, in order to obtain proper protection, that each motor should be separately fused, but unless each section of the whole system is properly laid out, and the protective devices which are connected in series are graded as a whole, it is impossible to foretell whether they will operate in proper sequence.

I agree that much less is known about rupturing capacity on low-voltage circuit-breakers than on e.h.t. equipment, but manufacturers are turning their attention more and more to this problem.

Referring to the author's illustrations of contactors, I am not quite clear as to what effect speed of break has on an a.c. circuit. We carried out some tests on 15-ampere tumbler switches for a lighting installation, and we found that slow-break switches produced little or no arcing as compared with the quick-break switch. From inquiries made in the trade I gather that there is some difficulty in getting supplies of this type of slow-break switch. I am surprised that some leading manufacturers have not yet standardized them; possibly there is a fear among some engineers of their being used on d.c. circuits where there is a mixed supply.

Mr. L. W. Norfolk: Will the author indicate whether in his opinion it is better to provide fuses in each starter than one set of fuses in the main incoming leads, as a protection against short-circuit faults?

Mr. A. G. Kidd: With regard to the experiment showing the working of a fuse in series with an overload coil, I notice that with a 10-ampere fuse on the first short-circuit the fuse stood the current, but on the second operation the fuse blew. How many operations have been carried out with the 15-ampere fuse? Have any tests been made to ascertain the number of operations the 15-ampere fuse will stand before it deteriorates?

I was interested in the last experiment performed by the author; what was the voltage across the contacts in this experiment, and what form of dust did he use?

Mr. G. Smith: Regarding the section of the paper dealing with ring mains; in view of the heavy short-circuits possible, would the author advise connecting small and fractional horse-power motors direct to the

* Paper by Mr. J. O. KNOWLES (see vol. 81, p. 145).

mains, or would he recommend breaking up the supply into sub-circuits from a series of feeding points tapped from the ring?

It is interesting to note that the fuse can still hold its own, and is actually recommended by the author as a last line of defence against heavy short-circuits.

I agree that a high-rupturing-capacity fuse and a good-quality time-limit overload device make a good combination. The paper mentions only thermal time-delays, and I should like the author's reason for this. Does he find that other types such as the oil-dash, clockwork air-brake, and disc motor, are unreliable owing to the effects of dust, dirt, and clogging oil?

Mr. D. H. Parry: I should be glad if the author would explain when it is correct to use a contactor and when an oil circuit-breaker.

I should like to support his opinion as to the disadvantage of using a switch on a 400-volt circuit to carry as much as 1 000 kVA. During the last 2–3 years I have had quite a lot of experience of the difficulty of maintaining large switches of 1 500 amperes.

As Mr. Bayley has pointed out, it is difficult for an industrial user to face using 3 000 volts when he has laid out his factory for 400 volts, but to the supply authority there are many advantages in the industrial user employing a higher voltage wherever he is going to take a large block of power. The difficulties of handing over to the consumer a block of about 2 000 kVA are not generally appreciated, and a lot of friction between consumers and undertakers would be removed if the advantages of using a higher voltage were better understood.

From my 10 years' experience of a power station having about 400 motors, I cannot recollect one instance of a switch blowing up, although during that time a number of switches were replaced because it was felt that they were out of date and their rupturing capacity was not satisfactory. Where trouble has occurred it has not been in the oil circuit-breaker, but usually due to the short-circuit arc finding its way on to the incoming terminals.

I have found it convenient to use 3-phase commutator motors of fairly large size, but manufacturers do not make these motors for voltages above 400 volts, and although we may desire to use 3 000 volts for motors of large size that is not at present possible. It would help if the author would suggest how the difficulty can best be met, so as to suit the requirements of the switchgear manufacturers, the motor manufacturers, and the users.

Mr. J. O. Knowles (*in reply*): I sympathize with Mr. Bayley's difficulty in securing room for substations on productive floor space. It is the perennial cry of electrical engineers responsible for installing distribution gear that space is given them grudgingly.

Mr. Bayley introduces reactance to reduce the possible short-circuit from a 2 000 kVA transformer. It is interesting to compare his views with those of Mr. Parry, who has had difficulty in maintaining l.t. switches of 1 500-ampere capacity (1 000 kVA). As Mr. Bayley points out, it is difficult to forecast future demands, and a 300-ampere 3 300-volt switch carrying 200 amperes has more margin for the future than a 1 500-ampere 400-volt switch carrying 1 500 amperes.

With regard to the rupturing capacity of l.t. breakers, I am very interested to note Mr. Bayley's use of 2 000-kVA transformers with a maximum l.t. short-circuit value of 15 000 kVA. If he can obtain good voltage regulation in spite of his reactances, he has solved the problem of using a large block of l.t. power without a heavy short-circuit value.

Mr. Parry has not had an l.t. switch blow up in 10 years, but he has taken the right precaution—replacement where the rupturing capacity of the switches was doubtful.

In reply to Mr. Norfolk, it is not essential to use short-circuit protection fuses in each motor circuit of a starter switchboard or multi-motor starting panel (in addition to overload trips in each starter circuit), but only to limit the number grouped on one fuse circuit in such a way that the fuses clear before the smallest starter opens on any fault exceeding the rupturing capacity of that starter. Nevertheless, if this recommendation is worked out in detail, it will be seen that before such grouping is possible the starter itself must have a rupturing capacity exceeding that laid down by B.S.S. No. 587.

In reply to Mr. Kidd, I used the same 15-ampere fuse in 11 lectures (and in a number of "rehearsals"), without deterioration. The 10-ampere fuse experiment was very critical. With a slight alteration to the circuit constants the 10-ampere fuse would not blow after many successive attempts, and with a slight alteration in the opposite sense the 10-ampere fuse would always blow the first time.

In the leakage experiment the voltage across the contacts was 230 volts at 50 cycles, and the "dust" was foundry graphite. With dust of higher electrical resistance the experiment would have taken longer.

In reply to Mr. Smith, fractional h.p. motors can be connected directly to ring mains, if connected through small fuses of high rupturing capacity, just as instruments on large circuit-breakers can be protected by high-rupturing-capacity instrument fuses; but it may be more economical (in supplying a number of small motors) to tap the ring main at a smaller number of points and redivide through fuse distribution boards.

I support either thermal or dashpot time delay on overload trips—according to the design and the location—neither is universally and intrinsically the "best." The same remark applies to the more expensive alternatives of "clockwork" and disc motor types of overload protection. Great reliability can be obtained with adequate knowledge and care.

With regard to contactors, the speed of break depends on the amount of roll before the contacts part, and on other factors such as spring pressure and moment of inertia, but I would confirm Mr. Bayley's report of reduced arcing by using slow break instead of quick break on 15-ampere switches. In a highly inductive circuit, however, and where highly magnetized iron is present, there may be added to the a.c. curve a d.c. component which troubles the short-break switch but not usually the contactor, the latter starting to open with a slow movement and then accelerating to a wide gap. In reply to Mr. Parry a contactor is designed for frequent operation and an oil circuit-breaker for infrequent operation. This does not mean that a contactor is necessarily unsuitable for infrequent operation.

Finally, the answer to Mr. Parry's last question is, I think, a hydraulic coupling and a 3 000-volt squirrel-cage motor, possibly of the 2-speed type.

DISCUSSION ON

"COIN MECHANISMS, WITH PARTICULAR REFERENCE TO ELECTRICITY METERS"*

NORTH-WESTERN CENTRE, AT MANCHESTER, 14TH DECEMBER, 1937

Mr. O. Howarth: I cannot quite understand what the authors mean when they talk of the influence of tariffs on design. It took the designer a long time to produce a two-part-tariff meter, and now one has been produced the fixed charge is always rated in pence per week, whereas no electricity supply undertaking's schedule gives a fixed charge in any other terms than so much per quarter.

It is a mistake to assume that there is less accounting with prepayment meters. The experience of most undertakings is that there is as much to be done and that the accountancy is quite as costly. Prepayment meters appreciably increase the capital cost of supplying the small consumer. The flat-rate prepayment meter does not encourage the increased use of electricity, and I think we can rule it out as a device for the future because it limits the use of electricity to lighting. The two-part and load-rate meters are perhaps the most useful because they tend to encourage the use of electricity by enabling people to use devices such as irons and bowl fires without increasing the cost out of proportion to what they can afford.

The multi-coin meter seems to be becoming rather popular, but a penny is far too small a coin for an electricity meter if extensive use is to be made of the supply. If consumers have to put pennies in prepayment meters frequently they get the impression that electricity is expensive, whereas the real difficulty is that they are putting in coins which are too small. Threepence or sixpence should be the minimum value of the coin used. In view of the Regulations under the Electricity Supply (Meters) Act, 1936, some different price-change arrangement, without the necessity for breaking the seals, is becoming desirable. If we break the seals we have to pay 3d. to the examiners. No doubt the meter designers will take heed of our requirements.

I do not agree with the authors' statement that the split series winding may not be used in consequence of the new Act. It is quite permissible to use it, provided we install another meter to register the units. The Act does not ensure that the correct price will be charged on a prepayment meter, but only that the measurement of units is accurately made.

Mr. J. E. Dyson: The problem of coin storage has not received the attention it deserves. Referring to the credit side, if the coin storage is made large enough the necessity for the coin-slot closing devices mentioned in the paper is obviated, since the chance of any consumer inserting a large number of coins at one time is, judging from our experience, exceedingly remote. With the advent of the fixed-charge meter, coin-storage has become a different question, particularly when applied to the debit side of the meter. This statement is based on my use of fixed-charge meters since 1935, a period which includes complete summer and winter seasons.

The amount of the debit allowed by manufacturers varies from 30s. down to 6s. If during the summer months a consumer becomes more than 1s. in arrears, he waits until the darker nights approach before he makes any use of the supply. Suppose the debit-storage maximum on his meter is 7s.: by inserting 8s. he is able to obtain a supply, although his arrears are obviously much greater than the 7s. indicated. The result of this state of affairs is a report to the meter department that the meter has failed to collect the full amount for which it was set, and the meter is consequently changed as faulty. It is put in the test-room, and no fault can be found. Then, by a process of elimination, the meter department find that during the summer months the consumer has not used the supply. It seems to me that some agreement is needed with regard to the amount of debit which is readable on a meter. I feel that the future of the fixed-charge meter depends largely on the way the system of charge is explained to the consumer. We have had a lot of misunderstandings with consumers owing to their not thoroughly grasping the fact that they have a certain weekly fixed charge to cover. Great care should therefore be exercised in the choosing of canvassers or development officers.

Mr. F. Ash: With regard to the discrepancies in penny diameters, I have seen several pennies of 1912 issue which had diameters corresponding to the maximum size, shown in Fig. 11, for the same year. These coins had not been mutilated in any way, and it was obvious that they had been over the normal diameter when originally issued.

In the diagram for the step-rate meter, Fig. 21(*h*), the change of rate is shown to take place between the coin receiver and the differential. Some supply authorities prefer this change-over device to be fitted between the meter register and the differential, as it then avoids the possibility of a consumer prepaying a large number of units at the cheaper rate just before the beginning of the next quarter. If this occurred, the object of the step-rate meter would be defeated.

It is stated in Section (3.34) that a tripping arrangement, shown in Fig. 31(*a*), throws a further load on the meter when it commences to operate. I would point out that the tripping device of this class shown in Fig. 24(*c*) tends to take load off the meter just before tripping occurs, owing to the side thrust of the trip arm on the sloping face of the differential platform.

It is stated that one of the disadvantages of the prepayment meter from the consumer's point of view is that the supply is interrupted without adequate warning.

* Paper by Messrs. J. Prince and M. Whitehead (see vol. 81, p. 515).

This is generally true, but I should like to point out that a prepayment meter with a warning device fitted has been on the market for some years.

Referring to Section (3.27), I think that the title "Unit charge depending upon short-time rate of consumption" is misleading. According to the "British Standard Glossary of Terms used in Electrical Engineering,"* the load-rate prepayment meter is "A prepayment meter such that the charge per unit is changed as soon as the load (power or current) exceeds a predetermined value." In my opinion it would have been better if a title based on this definition had been used.

Mr. C. F. Clifford: On page 534 it is stated that the first requirement of a fixed-charge price-change device is a variable-speed transmission over as large a range as possible: I suggest that the first requirement is a *positive* variable-speed transmission. I would draw the authors' attention to the change-speed device where two friction wheels are arranged in planes at right angles, the edge of one disc running on the face of the other, and the first wheel being capable of radial movement on the second to alter the ratio. In my opinion this arrangement would fulfil the first requirement specified by the authors, and yet I doubt whether they would approve of its use. Further, unless the drive is positive, the whole point of the synchronous-motor drive, i.e. its accuracy, is lost. As an instance of this, one may expect the errors on £100 collected to be within 0·1d. (0·0004 %) with positive drive and within £1 (1 %) with friction drive. I should like to know whether the authors agree that the word "positive" should have been included in the sentence to which I have referred.

Mr. A. M. Strickland: On page 516 the authors state that dust covers are sometimes fitted to coin slots. It appears to me that, if the slot is on top of the meter and it is used in a dirty atmosphere, dust and grit must undoubtedly penetrate and ultimately get into the working parts, causing wear. This would particularly be the case if the parts were greased, as they are in various types of meters. If the slot is at the side of the case and there is some projection above it, there is less tendency for dust to drop in. One would be inclined to say that some sort of shield should be fitted over the slot, but such a shield would have to be very simple; otherwise confusion would occur when the consumer wished to insert coins. It is interesting to note that all the coin tests that could be applied are not applied in the case of electricity meters. Possibly the reason is that, if the consumer inserts coins that are not correct, some attempt at recovery can be made; whereas in the case of a street machine, if a coin is inserted which the user thinks is genuine, although it is not, he may become very much annoyed if it is not returned. The majority of prepayment meters are not, therefore, devised for returning a coin that is not correct.

I am inclined to agree with the authors that the large credit-capacity feature is to be preferred to any device for preventing the entry of excess coins. I only know one case where a consumer put in so many coins that the mechanism got out of order; whereas with devices that close up the mechanism so that further coins cannot be inserted one frequently gets trouble calls. If a meter accepts a coin and does not pass it through, the consumer immediately draws the conclusion that he will not obtain anything in return for the coin, and he continues to complain until the people concerned give it attention. It is quite true to say that current designs of meters do not give a lot of trouble, but the users of the meters certainly do. One receives a lot of trouble calls in connection with prepayment meters, but it is necessary to use a little discrimination as to whether these calls are due to the meter, to attempts at fraud, or to ignorance on the part of the consumer.

The authors state that reading and collecting costs are increased by using prepayment meters. Is this statement the result of information collected over a wide field? Many engineers assert that collection by prepayment meters may be cheaper; I fail to see how this claim can be substantiated, because the collector often has to do a good deal of calculation, and tests have to be made to ascertain whether the meter is behaving correctly or not.

In the section on "Testing" the authors do not refer to the test of the fixed-charge part of the meter, and I should be glad if they would give their views on this. One of the methods of testing which may be adopted under the Electricity Supply (Meters) Act, 1936, is that of long-run dial tests. A certain load is put on the meter for a definite number of kilowatt-hours, and we have the option of arranging for a man to stand by, waiting for the end of the period, to check the number of units passed through and to switch off at the correct moment, or of developing some apparatus capable of automatically carrying out this function. In this connection we have endeavoured to press into service the standard prepayment mechanisms already available, and we have done so fairly satisfactorily.

Mr. J. M. Sanderson: From the supply authorities' point of view it is important that coins or materials shall not become jammed in the actuating mechanism. The words "coins or materials" are used to indicate the miscellaneous stuff that is inserted in machines—such as medallions, match stalks, tin discs, and buttons.

Fig. 2 shows that the coin receiver is followed by the coin test, for accepting or rejecting coins, and that this is followed by the actuation mechanism. I would point out that in most designs the test and actuation mechanisms are combined, and when incorrect coins are inserted the consumer may damage the mechanism by attempts to force the handle; this would be obviated if the sequence were actually as shown in Fig. 2. Only the correct coins would then pass into the part controlled by the consumer, which could not normally become jammed. All other coins would be rejected by another route, and would not pass through the actuation mechanism. Alternatively, the whole mechanism could be made so simple that no coin could become jammed in it, as it is more economical for the supply authority to instruct collectors to insist that tokens should be made good, or even to lose the value of the coin, than to send a meter mechanic to free a mechanism jammed by the insertion of false coins or materials.

With regard to the optional coin meter, it is found that in most cases this is used as a single-coin (usually a penny) meter, but it has a consistently higher liability to faults on account of the increased amount of mechanism

* B.S.S. No. 205—1936.

involved. This fact leads one to speculate whether this type of meter is justified, and whether the choice of a single shilling or penny meter is not more suitable.

Mr. W. Fennell: I should like to know what metering errors are introduced in practice by prepayment meters. Does the prepayment mechanism slow up the meter by 1% or 2%? I understand that the Electricity Supply (Meters) Act, 1936, takes no cognizance of prepayment mechanism. In other words, it deals with the meter as a meter; it finishes its functions at the indicating dial.

While I think that it is more important to make meters foolproof than fraudproof, there are exceptional cases. About 1900 I was concerned with some flats near London where the supply authority would not put in prepayment meters but the class of tenants was such that without prepayment meters no supply could be given. To overcome the difficulty I bought some Long–Schattner prepayment meters, paid "in bulk" on the maximum-demand system, and had the money collected from the prepayment meters. I felt fairly safe, as the tenants would normally have to account for any foreign coins, etc., found in these meters; but after some "moonlight flits" had occurred I found that the pot which was intended to hold silver coins was full of shot, or farthings. The tenants had gone, and I was left with a deficit after paying what was due to the supply undertaking.

Some Mordey–Fricker prepayment meters installed in 1910 have only been taken off the circuit of our d.c. areas within the past 2–3 years. They have given good service except for one point. At one period it was found that if the consumer loaded the meter with money the copper strip was pushed forward so much that it buckled, and short-circuited to the anode, allowing him to obtain as much electricity as he liked. This defect was soon dealt with, and the meter survived for d.c. work.

I think meter rents are easily justified. We have a commodity, electricity, to sell, and the meter is an apparatus for measuring the consumption. Under the Electricity Acts the meter is the consumer's, but the supply undertaking is required to provide meters for hire to such consumers as wish to hire them. The consumer has every right to provide his own certified meter, in which case the rent is replaced by capital and maintenance charges. If there is a meter rent, each consumer pays roughly in proportion to the service rendered. Compare the case of a consumer who uses 1 000 units a quarter with that of his nextdoor neighbour who uses very little electricity. If there is a meter rent, each pays the same amount for the use of the same size of meter, and this is equitable. If the cost of meters is included in the unit charge for electricity, the first consumer pays too much and the second too little.

In a paper read a short time ago, Mr. Pickles* showed how very important the two-part-tariff prepayment meter is in dealing with a rural area, and I think that this type of meter will be the sheet anchor of our future domestic business in this country. It is outrageous to charge a consumer through a prepayment meter 6d. or 8d. a unit because, not having adopted the two-part-tariff prepayment meter, we cannot charge less than the ordinary lighting flat rate.

95 % of Mid-Cheshire consumers are on a two-part tariff using quarterly meters, combined, in some cases, with monthly collections on account. We have been trying to find a suitable two-part-tariff meter to adopt.

One cardinal point, hitherto not provided for, is that the prepayment mechanism must be quite distinct from the meter, so that the new burden which has been placed upon us in the way of meter testing and sealing will not involve our paying 3d. to the Electricity Commissioners each time we have to open the meter to remove a bad penny. Given the right type of two-part-tariff meter, supply undertakings will double their output in any area where there is a reasonable proportion of working-class consumers. By installing the two-part-tariff meter we are now able to offer attractive terms to the small consumer who has hitherto used gas.

Mr. F. H. Batt: The paper makes it quite clear that without the advantage of the prepayment meter it would be extremely difficult to deal with the type of consumer who makes payment in small amounts.

Any comparison made between accounting systems, also machines for dealing with money after receipt, which may be very similar, should not be confused with comparisons of the difficulties of collection. The important comparison is the cost of collection from the consumer by the prepayment meter with the cost of collection, from that particular class of user, by other means. Collection by other means would, I think, be practically impossible.

Mr. J. Sumner: It would be interesting to know, if prepayment mechanisms are to come under the Electricity Commissioners' control, whether they would accept the authors' $\pm$ 3 % tolerance per coin. Very little is said in the paper about the electrical circuit employed for testing purposes, and I should like to know of any recent developments on these lines. If makers adopted the idea suggested, of providing special means to facilitate the mechanisms being rotated by hand, prepayment-meter tests could be carried out more quickly.

Messrs. J. Prince and **M. Whitehead** (*in reply*): A wide diversity seems to exist between individual requirements in points of detail, and it is mainly, though not entirely, these points of detail which have emerged in the discussion.

Mr. Howarth states that he cannot quite understand what is meant by the influence of tariffs on design. We believe, however, that he would be one of the first to agree that in charging for electricity the first thing is to fix a tariff, and then to try to design a meter which will meet that tariff exactly, rather than to take the nearest available meter and modify the tariff. This being agreed upon, it follows that the tariff has a very great influence on the design. In actual practice there will naturally be an appreciable time-lag between the demand and the appearance of the meter, even where the approximate method of construction is known.

Regarding the two-part tariff setting being easier in terms of pence per week, whereas an undertaking's schedule gives the fixed charge in terms of so much per quarter, it is felt that this is not a very important point, and the charge might just as easily be expressed one way as the other, except that a much finer scale is possible where the amount is expressed per week. We share Mr. Howarth's view that the tendency in the future will probably be towards arrangements for carrying out

* *Journal I.E.E.*, 1938, vol. 82, p. 333.

price-changes more easily, as a result of the Electricity Supply (Meters) Act, 1936.

We agree with Mr. Dyson that a large coin storage is advantageous in a good many cases, and that where the debit storage is limited loss may occur with certain consumers. Some reference to these points occurs in the paper under the heading " Storage " (page 529).

Mr. Ash refers to the **1912** penny, which is by now fairly well known amongst those who use coin mechanisms. An appreciable number of **1912** pennies (but by no means all) were struck with excessive diameter.

We agree that, in cases where the price change-over takes place between the differential and the meter, the possibility is avoided of the consumer prepaying a large number of coins immediately before the end of the quarter, and thereby avoiding the higher-price units in the next quarter. The difficulty, however, where the price change-over occurs between the coin receiver and the differential can, of course, be overcome by the collector refunding the existing credit.

It is possible, as Mr. Ash points out, that the type of tripping device illustrated in Fig. 24(*c*) would tend to take the load off the meter just before tripping, and therefore in some measure compensate for the increased load placed upon the meter immediately before tripping. Any variation in load, however, would tend to affect the accuracy of units per coin. He points out that prepayment meters fitted with warning devices have been on the market for some years, but we feel it would be generally agreed that these warning devices have many serious disadvantages; for example, operation at night.

We cannot agree that the title of Section (3·27), namely, " Unit charge depending upon short-time rate of consumption (load rate)," is misleading because it is qualified by the term load rate in brackets; this term, as Mr. Ash points out, is well defined in the " British Standard Glossary of Terms used in Electrical Engineering." The first portion of the title is the one we prefer.

Mr. Clifford makes a comment in regard to our statement of the first requirements of a charge-change device for a fixed-charge meter, to the effect that the word " positive " should be introduced in the term " variable-speed transmissions." Such a construction was in fact intended, and we therefore agree that it would be better to include the word " positive " in this sentence.

We must thank Mr. Strickland for his remarks in amplification of the paragraph devoted to coin receivers. His views are exactly in accord with our own. It is quite true that all the tests which could be applied to coins are not so applied in a prepayment meter, and we feel that the reason is, as Mr. Strickland surmises, that the possibility of the recovery of the correct coins in a meter installed in a private dwelling is very much greater than in a public coin mechanism, coupled with the fact that the prepayment meter must be sold at an economic price. His experience with large credit-capacity meters and meters fitted with coin-entry closing devices is very useful and should form a guide in future designs. His comment regarding the amount of trouble given by prepayment meters and the necessity for discrimination in the source of these faults is very refreshing.

The statement on page 541 that rating and collecting costs of prepayment meters are increased is not based on own practical experience, but on information collected from a number of supply undertakings.

The question of checking the fixed-charge portion of a prepayment meter was raised by Mr. Hunt during the discussion in London,* and we believe the reply to that question will answer the point raised by Mr. Strickland. As is stated in that reply, we know of no method that is both simple and comprehensive.

Mr. Strickland's description of the way in which he has applied a prepayment meter to facilitate the dial testing of all types of meters under the Electricity Supply (Meters) Act, 1936, is very interesting. Since his contribution to the discussion he has published an article† which deals more completely with this application.

Mr. Sanderson speaks at some length on the trouble experienced when consumers insert wrong coins or foreign material, and he suggests that if the coin receiver, coin test, and accepting mechanism, were completely separated (as shown in Fig. 2) less trouble would be experienced. With this we agree, but we would point out once again that such construction would force up the price of the meter above the economic level. Mr. Sanderson also speculates as to whether the optional coin meter is justified, because it is found in the majority of cases that it is used largely as a penny coin meter. To this point we would reply as we did to Mr. Hunt in London, but we are not quite certain how this information should be interpreted; because with a 1d. and 1s. meter the amounts of money collected from the two coins are only equal when the percentage of penny coins is between 92 % and 93 % of the total number of coins.

In reply to Mr. Fennell, the error introduced into the measuring element proper of the meter by the mechanical load imposed by the prepayment mechanism depends upon a number of factors, but in all cases upon the denomination of coin, the price per unit, and the rating of the meter. The average working figure would be 1 % on 1/20th load, and due cognizance of this is taken in the current British Standard Specification,‡ where the case of the prepayment meter is specifically mentioned and an additional tolerance of $\pm$ 1 % allowed.

His experience on the subject of fraud and his views that it occurs only in exceptional cases are very interesting. Similarly, his argument supporting meter rents appears to be just and well reasoned. Finally, we must thank him for his very able support of our general views on the subject of the justification of prepayment meters.

Mr. Batt stresses the same point, and we agree with his comments that comparisons between accounting systems are irrelevant where the prepayment meter is the only means of collecting revenue from a consumer.

In reply to Mr. Sumner, we do not know whether the Electricity Commissioners will accept our tolerance of $\pm$ 3 % in units per coin, but we would state that whilst this figure is perfectly reasonable for the medium and lower prices per unit, figures much higher than this are experienced with higher-price-per-unit meters.

Regarding accelerated testing in manufacturers' works, this is carried out in certain instances, but only in part; almost invariably the actual tripping of the switch is carried out electrically.

* *Journal I.E.E.*, 1937, vol. 81, p. 548.
† *Electrical Review*, 1938, vol. 122, p. 719.
‡ B.S.S. No. 37—1937, p. 18.

DISCUSSION ON
"HIGH-SPEED PROTECTION AS AN AID TO MAINTAINING ELECTRIC SERVICE FOLLOWING SYSTEM SHORT-CIRCUITS"*

NORTH-EASTERN CENTRE, AT NEWCASTLE, 14TH MARCH, 1938

Mr. H. Leyburn: The impression I got from reading the paper was that high-speed protective systems must be something new, necessitated by the growth of modern networks. This was confirmed by discussion of the paper with supply engineers, who were inclined to view it with some suspicion as highly technical, and as dealing with subject matter they were not familiar with. On my pointing out to them that they had been using high-speed protective systems in their own networks for many years they were at first rather incredulous, but were eventually convinced when I reminded them that pilot-wire systems have been common in Great Britain for about 30 years.

In view of this, perhaps a few words about the historical background and the general perspective of the paper will not come amiss. Pioneers of unit protective systems in Great Britain like Merz, Price, Clothier, and others, realized as far back as the beginning of this century that fast clearance of faults is essential for continuity of supply in interconnected networks. The pilot-wire systems established in those days were of what was called the instantaneous type, and fast operation has always been one of the main features of later systems based on them. Examples of the time of operation of relays used with such pilot-wire systems for many years are shown in Fig. A, which indicates that except for an inverse time-lag at small fault-currents the time of operation is well below 0·1 sec. The important point is that the curves represent the overall operating-time of these long-used pilot-wire protective systems. I disagree with the authors' remark on page 232 that "it has been the practice in the past to introduce a slight artificial delay"; Fig. A shows that this has not been usual, at least in the systems whose performance it illustrates, e.g. the original Merz–Price system, the split-pilot system, the Solkor system, and pilot-wire systems for generators and other apparatus.

High-speed pilot-wire systems having been firmly established in Great Britain, the historical development was then as follows. With the advent of large networks including long overhead lines both in Great Britain and in the United States, protective systems, e.g. distance systems and interlock systems, were introduced with the primary object of either eliminating pilot wires altogether or making it possible to reduce their cost. They achieved their object, particularly in overhead-line networks, but they were inherently slower than balance pilot-wire systems, and after they had been installed for some time it was found that speeding-up was necessary to bring them more into line with the older pilot-wire systems as regards time of operation. As a result, high-speed distance and interlock systems were developed.

If the paper is viewed in the light of historical development, it becomes clear that, of the protective systems described in Section (4), the pilot-wire systems illustrated in Figs. 6 to 12 have been designed primarily in order to come into line with the already widely-used pilot-wire systems having somewhat similar times of operation. On the other hand, Figs. 13 to 19 illustrate interlock and distance protective systems to which high-speed operation has only been applied recently. These have not previously been described in detail, but they were recently referred to and explained in principle in the *Journal*.†

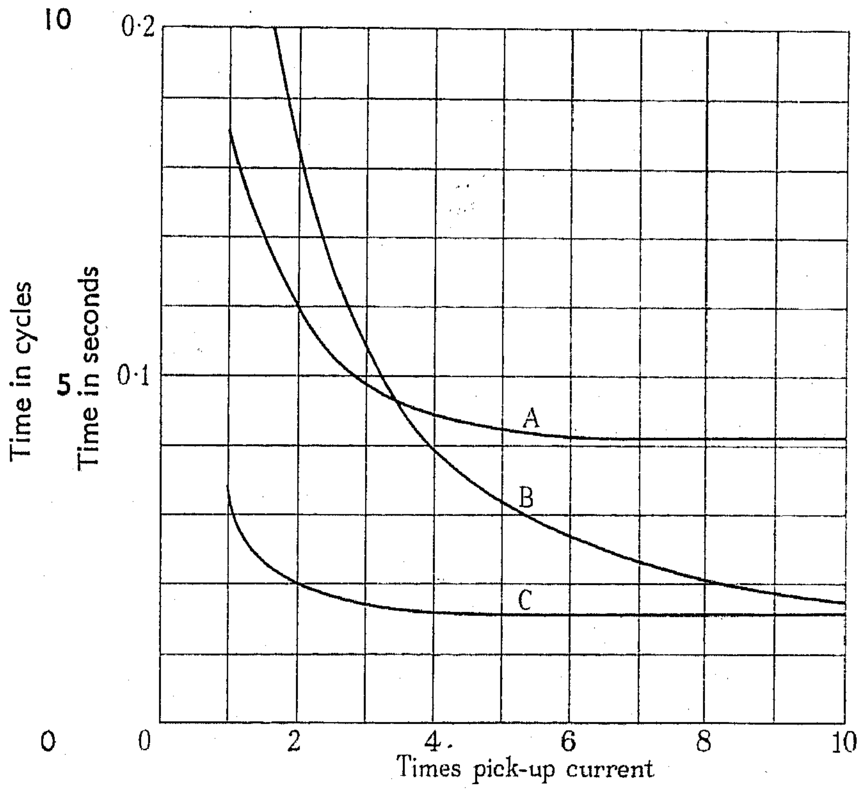

Fig. A.—Typical time/current curves of protective relays in common use in Great Britain for many years.

A. Rotary electromagnetic relay.
B. Hand-reset electromagnetic relay.
C. Self-reset electromagnetic relay.

It would have been well to include in the paper a definition of high-speed protection. Although the authors give some typical relay operating times on page 231, I cannot discover exactly what they mean by high-speed protection. In order to avoid confusion I suggest that the term "instantaneous" as applied to a relay or to a protective system should denote that operation is not purposely delayed, and that it should be regarded as an omnibus term including as subdivisions: (1) ultra-rapid, up to 0·5 cycle; (2) high-speed, over 0·5 cycle up to 5 cycles; and (3) fast-acting, over 5 cycles up to 15 cycles; all these

* Paper by Messrs. T. W. Ross and C. Ryder (see page 228).

† H. W. Clothier, B. H. Leeson, and H. Leyburn: "Safeguards against Interruptions of Supply," *Journal I.E.E.*, 1938, vol. 82, p. 445.

being operating-times at 10 times the minimum operating-current, with possibly a specification of another set of times corresponding to some lower operating-currents. Relays in the first subdivision would usually be thermionic, whereas those in the second and third subdivisions would be ordinary electromagnetic or induction relays.

Turning now to the details of the paper, I note that in the Translay system illustrated in Fig. 6 the authors propose an electrically-tuned restraining-coil with the object of ensuring stability under oscillatory through-fault conditions. The problem of oscillatory stability came to the fore some time ago as a result of investigations by Mr. B. H. Leeson, who also suggested ways of solving it.* The means finally adopted, which has been in successful use for some time (e.g. in the split-pilot and Solkor systems), was to tune the operating coil of the relay electrically so that it would respond to the fundamental frequency only. In my view, this is a more straightforward way of attacking the problem than that of the authors, since the tuning condenser completely by-passes harmonic currents, and so makes it unnecessary to calculate their possible effect on the protective system. For example, with the authors' method a condition is possible in which the current in the relay due to an internal fault is so counteracted by the oscillatory current in the restraining coil that operation is prevented. In this connection is the condenser which the authors use for tuning the restraining coil always of the same size, or does it vary in size with the length of feeder?

Since the Translay relay is of the wattmeter type it is necessary, as Fig. 10 indicates, to use additional inter-tripping relays and batteries in order to ensure operation of the relays at both ends. With the plain current-operated relays used in other systems such a complication becomes unnecessary, because operation at both ends is obtained no matter whether the fault is fed from both ends or from one end only.

I note that credit is given to the United States for originating the carrier-current protection described on pages 236, 237, and 238. The fact is, however, that the first successful carrier-current protection was installed in this country in 1931 for a 132-kV feeder of the Central Electricity Board, and its success was entirely due to the adoption of the interlock (or, as the authors call it, the locking) principle, on which subsequent installations in the United States and in France were also based.

It is difficult to comment on the curve shown in Fig. 18 since no times of operation are given. The stepped characteristic is now becoming generally accepted, and was illustrated in the paper by Messrs. Clothier, Leeson, and Leyburn.†

I would stress the need for simplicity, particularly in pilot-wire systems, in which it is comparatively easy to obtain all the desired features without complication. The schemes and characteristics illustrated in Figs. 10 and 11 do not in my opinion comply with this requirement, since they use more relays than are absolutely essential; and the compensating devices illustrated in Figs. 6 and 7 also seem to lack simplicity.

I have disagreed with the authors on many points, but I wish it to be clear that in the main aim of speeding-up protective systems they have my entire support.

* British Patent Specification No. 227523. † *Loc. cit.*

Mr. G. W. B. Mitchell: System instability is rare in this country, for reasons which are apparent after a study of the paper, but this does not mean that high-speed protection is unwanted in Great Britain. I think that this form of protection is justifiable on important networks on the score of the reduction of damage to apparatus alone. In addition, the reduction in shock to the system which is obtained is very desirable, even though the shock experienced with ordinary clearance-times may not actually cause instability.

A brief reference is made in the paper to motor protection, a matter which is still somewhat unsatisfactory from the technical point of view owing to the difficulty in providing complete cover for all starting, running, stalling, and fault conditions without undue complication. Elaborate protection on motors cannot usually be justified economically.

I agree that under-voltage releases are a prolific source of trouble during otherwise comparatively harmless system disturbances. Improved service can be obtained by adopting the author's suggestion that these should be time-delayed, but I would go further and suggest their omission altogether. I do not agree that it is necessary to complicate back-up protection by making this of the impedance type. The present practice of utilizing time-delay over-current relays is reasonably satisfactory as these are usually given high current and time settings, and unwanted operation is therefore unlikely to occur.

I am surprised that the authors maintain that induction-type directional relays can be made to operate satisfactorily in times of less than 1 cycle, and I should be glad if they would give details of the tests they have carried out in this connection. Up to now, it has been believed that such relays may operate in the wrong direction during the first cycle after the occurrence of a fault.

I should like to know what advantages are claimed for the system of overall differential transformer protection described on page 234, as compared with separate overload and restricted earth-leakage protection of each winding of the transformer. The latter gives instantaneous protection for all earth faults in a simple manner, and enables settings of the order of 20 % of normal full-load current to be secured with complete stability on through faults. With the overall system, however, quick clearance can only be obtained with high current settings, and the lower settings involve long relay operating times. The only advantage I can see in the "overall" type is that it provides better phase-fault protection. It is, however, quite exceptional to experience a phase fault in a transformer which is not also an earth fault. Similarly, I cannot see the justification for complicating ordinary high-speed restricted earth-leakage protection in the manner indicated in Fig. 12. Experience shows that the simpler arrangement is quite satisfactory.

I should like to know whether the authors have considered the problem of providing inter-tripping facilities in conjunction with high-speed carrier protection. This may be required in certain cases, but it introduces one or two technical difficulties.

Prof. J. C. Prescott: In regard to Figs. 2 and 3, I see from Appendix 1 that the deflection θ is given as equal to half the difference in angular velocity multiplied by the time-interval during which this difference occurred.

This expression, it seems to me, is only justified if the velocity is increasing uniformly, which would imply a constant acceleration. Acceleration is proportional to $P_1 - P_0$, and it is assumed that P_0 is constant. If the acceleration is to be constant, therefore, P_1 must also be constant, but the curve in Fig. 5 shows that the power (P_1) is decreasing rapidly during the first part of the short-circuit period. Perhaps the integration of the velocity curves has been carried out by a step method in which the differences ($\omega_0 - \omega_1$) and ($t_0 - t_1$) are small.

I have also encountered some difficulties in Appendix 2. Should not the last term in equation (4) be $R(E_a/E_b)$? If this is so, the expression for the synchronizing power available half-way along the line is not that given by the equation immediately preceding Fig. 21. The power transfer be ween the two machines has a maximum value which depends upon the value of α, and this maximum may again be differentiated with respect to X. P_r is a maximum when $\tan \alpha = X/R$, and substituting this value for α in the P_r equation we can obtain a second maximum if R is kept constant, when $X = \sqrt{3}R$. It may be of interest to remark that this second maximum occurs with the relation between R and X which gives the maximum inherent instability (due to negative damping) for a machine without damping grids.

Mr. E. G. Swangren: I am particularly interested in that part of the paper dealing with system stability and synchronizing power.

On reading the paper one is apt to get the impression that the system stability is easily upset owing to the disturbance caused by a short-circuit, and that this applies to every high-voltage system; it is only in the Conclusion (page 240) that the authors state that conditions in this country are such that instability is seldom approached.

They mention that system disturbances arising from short-circuits are solely due to the effect the latter have upon rotating machines; this is quite correct, but the effect really depends upon the type of interconnection which exists between the stations. To take a practical example, I should like to describe the experience the North-Eastern Electric Supply Co. has had in running power stations in parallel. This system has three large power stations and a number of smaller stations, all running in parallel. The main rotating machines are, of course, the power-station generators, and during the last 15 years we have had no trouble with generators falling out of step due to a system short-circuit. Individual generators in a power station give no trouble when running in parallel under all conditions, this being due to the improved design of the generators themselves. Our experience, therefore, is that there is no difficulty in running power stations in parallel provided the stations are suitably interconnected. Instability will only occur on a system where the amount of interconnection between the stations is comparatively small.

On the same system we have now practically dispensed with synchronizing points, and synchronizing is done only at the power stations. Apart from the power-station generators very little synchronous plant is now connected to the system; most of the running substations, as we used to call them, have been changed over to static equipment.

The angular displacement of generators, whether running in parallel on the same busbars or in parallel through interconnecting lines, is always a function of the tie-line impedance, and the authors state that there is very little danger of instability provided the angular displacement does not exceed 100 electrical degrees. I should like to ask whether this is a calculated figure or one obtained from practical experience. I would add that I am rather doubtful whether using high-speed protection is the best way to deal with the problem of instability.

The difficulty in connection with any calculation dealing with stability is to obtain the percentage impedance of the interconnecting network; this is comparatively easy when one is considering a small system, but another problem altogether when a large system is in question.

I should like to ask what procedure is now adopted for calculating the synchronizing power required to keep, say, two stations in parallel, in view of the fact that a figure of 100 degrees displacement is now the agreed maximum figure. Are the calculations based on this figure?

The problem of keeping motors running during a system disturbance seems to have been taken care of by the manufacturers of motor switchgear, as very little trouble is reported.

The authors' remarks on back-up protection give the impression that this type of protection should be avoided. I agree, of course, that such protection should be very carefully applied. On our system we use it extensively on feeders and generators at the power stations and on feeders at main transmission centres, and it has given practically no trouble. It is used for sectioning purposes as laid down in the Electricity Regulations, and when settings are carefully calculated, taking into account all factors connected with the short-circuit conditions on the system, this type of protection gives very good service. The back-up protection is generally applied as a safeguard under busbar-fault conditions, or as a safeguard against faulty operation of patented protective apparatus. It may, of course, be dispensed with in the future when we have been convinced of all the merits of busbar protection.

In connection with the method of pilot-wire lock-in protection shown in Fig. 13, I should like to ask the authors whether any special protection is required in the pilot-line circuit apart from the surge-guard relay to prevent faulty operations during a system disturbance. A more complete description of the guard relay and its connections, and a statement as to the time delay figure applied, would be welcome.

Mr. W. N. Waggott: On page 231 the authors record that special circuit-breakers are now available which can clear a short-circuit in 0·06 sec. I assume overall tripping-time is referred to, and I doubt whether any oil circuit-breaker in service in this country is equal to such a performance. Few oil circuit-breakers appear to be capable of clearing a short-circuit in even the extended period of 0·16 sec. referred to by the authors. In the same section of the paper reference is made to improving the performance of conventional oil circuit-breakers by fitting arc-control devices and modifying the tripping mechanism. Care is necessary if modernization work of this nature is to produce the desired result. Arc-control devices impose a heavy impact duty on their supporting

insulators, and in general it will be found that special supporting insulators are necessary. Experience has shown that porcelain is of doubtful value for supporting arc-control devices in oil circuit-breakers of high rupturing-capacity. It is also important that such oil circuit-breakers should be rigidly secured to substantial foundations. It has been found that certain high-speed tripping mechanisms carry with them a tendency to unwanted tripping of the circuit-breaker. This is probably due to the light setting of the tripping latch adopted. The use of higher tripping currents may, as the authors point out, necessitate the introduction of auxiliary tripping relays. As the operating time of these auxiliary tripping relays must add to the overall tripping time, there appears to be no advantage in adopting this arrangement.

I question the authors' recommendation that back-up protection should be of the time/distance measuring type. By the very nature of its duty back-up protection should be of the simplest pattern, and this requirement is not met by protective gear of the type recommended. Overload protection is invariably used for back-up purposes, on account of its simplicity.

Messrs. T. W. Ross and **C. Ryder** (*in reply*): Mr. Leyburn has devoted most of his remarks to an elaboration of the second paragraph of the Introduction to the paper and to a plea for simplicity. The protective systems illustrated in Figs. 6 to 12 are designed for faster operation than the pilot-wire systems he mentions. The Translay system illustrated in Fig. 6 is really very simple in comparison with others and it is quite unnecessary to make calculations of the type visualized, since the condenser is always the same size. We would also assure Mr. Leyburn that there is no likelihood of operation being prevented by the action of the bias coil. We purposely omitted from the paper any definition of the term " high speed " as applied to protection, because the term is purely relative; on the other hand, the order of relay operating times is indicated, and while some classification might help to bring certain relays within the high-speed category, the issues involved remain unaffected.

The scheme illustrated in Fig. 10 provides for the possibility of one circuit-breaker tripping and interrupting the fault current before the relay at the other end operates. Such an arrangement is necessary with any type of relay where time-delay is introduced to take care of magnetizing-current surges.

Although low-speed carrier-current protection was installed in Great Britain in 1931, there is no doubt that high-speed carrier-current protection was in use in the U.S.A. for several years prior to its recent introduction here. It is also a fact that, for several years prior to 1931, American engineers had been experimenting with carrier currents as a means of protecting transmission lines.

We agree with Mr. Mitchell that a reduction in the damage to apparatus is an important factor in favour of high-speed protection, even though in certain cases the problem of system stability may not arise.

From the technical aspect complete motor protection can be assured, although it is appreciated that with small motors the economics of the situation may dictate a limitation in the safeguards afforded.

We are surprised that doubt should exist regarding the operating time of induction-type directional relays. Many tests have been carried out, and oscillograph records taken, showing times well under 1 cycle. Several relays of this type have been installed on the C.E.B. system.

The advantages of differential transformer protection are (*a*) quicker phase-fault clearance, and (*b*) discrimination between faulty and healthy paralleled transformers without directional relays. We agree that phase-to-phase faults are less frequent than earth faults, but surely it is the protective engineer's duty to provide against such contingencies, particularly as experience repeatedly shows that it is the unexpected faults which give rise to the greatest disturbance.

The justification for the schemes illustrated in Fig. 12 is that in certain cases, owing to limitations imposed upon the design of the current transformers, it is difficult to obtain complete discrimination with reasonably low relay settings.

Intertripping facilities with high-speed carrier protection are quite possible with coded signals.

Prof. Prescott's assumptions regarding the integration of the velocity curves are correct. The last term in equation (4) of Appendix 2 has inadvertently been misstated and should read $R(E_a/E_b)$; this, however, does not affect our final expression for available synchronizing power.

Mr. Swangren's remarks are very interesting and in the main bear out our own conclusions regarding stability. We agree that complications arise when a large system is under consideration, although the general method of determining phase displacement is similar to that described. Sufficient margin must always be allowed over and above the displacement brought about by load transfer to permit of the possibility of additional displacement occurring during short-circuits.

We did not think it necessary to make any reference to surge protection of the pilot wires in Fig. 13, but any of the well-known features may be applied if necessary. The function of the surge-guard relay is to prevent unwanted operation of the directional relays during surging between generating stations. Its operating time is of the order of 0·3 sec.

Mr. Waggott's remarks in connection with circuit-breakers are of interest and, in general, we are in agreement with them. There is no fundamental reason why high-speed tripping mechanisms should introduce a tendency to unwanted tripping. On the contrary, it is possible to design mechanisms which are extremely stable.

Several speakers question our recommendations regarding back-up protection, but recent events have borne out our contention that time-delay overcurrent relays fail entirely in certain conditions. We are therefore more firmly convinced than previously that the time-distance relay provides a satisfactory alternative.

THE CENTRALIZED CONTROL OF PUBLIC LIGHTING AND OFF-PEAK LOADS BY SUPERIMPOSED RIPPLES

By H. PURSLOVE BARKER.

(*Paper first received* 12*th November*, 1937, *and in final form* 23*rd March*, 1938; *read before the* TRANSMISSION SECTION 11*th May*, 1938.)

SUMMARY

It is the author's purpose in this paper to discuss the problems of collective control on modern supply networks, to examine various alternative methods, and to explain how, by the aid of superimposed high-frequency signals, any distribution network may be used as a signalling system which will enable a supply undertaking to exercise remote control of consumer circuits from its own power station.

He concludes that recent developments in this field have placed in the hands of the supply industry a powerful weapon with which to attack the economical development of heating loads, as well as providing an elegant solution to commonplace difficulties of street-lighting control, to which the supply industry has become accustomed but not reconciled.

The special application of superimposed control in war time for the extinction of public lighting and for the dissemination of warning signals is not discussed in great detail, as such problems are of political rather than technical interest.

As to terminology, control systems using superimposed signals are variously referred to as "carrier control," "phantom circuit control," and "ripple control" systems. Of the three, the author prefers "ripple control," since it avoids confusion with terms more properly applicable in other fields, yet gives a correct picture of the method itself.

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(1) INTRODUCTION

Since the earliest days of public electricity supply, many have sought a convenient method for simultaneously switching a large number of low-tension circuits from a central point.

The need for such centralized control systems commenced when electricity was first adopted for street lighting.

It developed further when the exigencies of maximum demand led supply authorities in many countries to regulate their maximum-demand commitments by two-rate metering and discreetly-devised off-peak tariffs, both methods requiring for their economical development a centralized control system.

Until 10 years ago no method of centralized control, capable of general adoption on extensive networks, had been produced.

The development of the clock switch, and its extensive application to street-lighting control, have been fundamentally due to the absence of reliable and economical alternatives, and although the time switch has to-day reached a high degree of mechanical perfection it can, by its nature, only be applied to services where the switching routine is pre-arranged and invariable.

There are, however, very few applications of automatic switching where the time of the day is the one and only element which *should* regulate the operation of a switch. In the case of street lighting, for example, the correct time to switch on may be determined by the incidence of fog, war, or other emergency.

Similarly, by nature the control of off-peak loads demands human judgment, as a time switch cannot discern the capricious variations of maximum demand, and cannot be relied upon to produce the desired economies without effecting interruptions of supply of longer duration than would be necessary if human judgment were the controlling factor.

(2) VARIOUS METHODS OF COLLECTIVE CONTROL

Any system of centralized control must take its place in one of these two categories:

Category (*a*):—Methods in which the controlling signal, in whatever form it may be, is conveyed to the points of reception by a separate network of conductors provided solely for the purpose.

Category (*b*):—Methods in which the controlling signal is conveyed by the feeders and distributors of the supply network itself.

Category (a).

Systems employing pilots are widely known and do not present any problems of technical novelty, as a system of pilot conductors can be used for the operation of relays or contactors, and discriminating control can be effected by the use of impulses, variable-frequency signals, polarized relays, and other means.

It is, however, very rare in practice for a distribution authority to provide a complete pilot system throughout the whole network.

Where centralized control is provided by means of a

special network of conductors, it is normal for these conductors to carry the controlled load itself, rather than a pilot current for operating contactors.

Everyone is familiar with the practice of laying separate cables from the substation for feeding public lighting only, and providing one master control for the whole circuit.

Although in operation these systems may be irreproachable, it is quite uneconomic to lay a separate system of conductors to provide centralized control of any service on an existing network, for although the cost of the actual cables is small the cost of laying them is prohibitive.

The present tendency is towards Category (*b*), viz. systems in which the network itself is used for the conveyance of signals which can reach every consuming outlet of the system and operate relays located wherever control is required.

Category (b).

There are three conceivable methods of utilizing an a.c. network for the transmission of a control signal: (*a*) By effecting a momentary variation of the system frequency; (*b*) by momentary variation of the system voltage; and (*c*) by superimposed signals.

Method (*a*).—This method might have been practicable 30 years ago, but it is quite impossible to-day, since to effect a distinguishable signal the supply frequency would have to be raised or lowered by at least 1 %, which presents insuperable difficulties and objections on large interconnected systems.

Method (*b*).—This is more feasible, although extremely difficult to apply in practice.

Apart from the physical difficulty of effecting a momentary variation in supply voltage, any system which involved a momentary variation of the consumer's voltage would necessitate the use of some form of relay which would be sensitive to momentary voltage variation (necessarily within a closely prescribed limit) but which could at the same time discriminate between a deliberate voltage variation and an accidental one caused by a fault on the system or other disturbance. Such a method must be ruled out.

Method (*c*).—It was realized many years ago that the solution must be to impress on to the distribution system momentary signal currents distinctive in form or frequency from that of the load, in such a manner that the signal should permeate the whole distribution system and be received by, and cause to operate, suitable relays located at distant points.

The aim, which has been completely attained, has been to devise systems which will:—

(*a*) By the aid of a central transmitter propagate signals over a network, between which reception relays can discriminate, so that, for example, one signal will turn street lights on, another control off-peak loads, and so on.

(*b*) Provide a superimposed signal which does not interfere with the consumer or any apparatus he may employ.

(*c*) Operate reliably an unlimited number of inexpensive relays.

The early pioneers in this field were led astray by the apparent simplicity of the problem, and from the end of the last century until about 1925 the history of superimposed control was that of an almost continuous series of disappointments.

Among the pioneers, pride of place must be given to Messrs. W. Duddell, H. W. Hancock, and A. H. Dykes, who in 1912 outlined clearly the principles which could be successfully employed,* and many will remember the "Olipell" system which was much discussed immediately after the War.

The systems which have been proposed in the past are, however, so numerous that it is not possible to mention them all, and it is the author's intention to comment only on those systems which can be or have been realized on a practical scale.

Superimposed control systems may be divided into two classes:—

(i) Systems which require the location of the signal transmitters in substations.

These may be termed "localized systems," since each transmitter will only serve a limited low-tension area.

(ii) Systems in which a single transmitter is located in the generating or bulk-supply station and can cover a large network, the signals traversing the high-tension system and substations before reaching the reception relays on the low-tension networks. These are termed "centralized systems."

(3) COLLECTIVE CONTROL BY SIGNALS FROM THE SUBSTATION

The Earth-Return System

This method, which appears to owe its origin to Brown and Routin in 1897, is illustrated in principle in Fig. 1, which shows a low-tension distribution network fed from the low-tension windings of a substation or a star-wound alternator.

The principle of this method is analogous to any single-wire telegraph or telephone system, in which a single conductor connects the points of transmission and reception and the earth is used as a return circuit.

In this case the distribution network as a whole is considered as a single conductor which can be used to convey an audio-frequency signal or impulse to relays connected between the network and earth.

The system is used to-day for the control of street lighting, and comprises a single-phase audio-frequency alternator or oscillator connected in the manner shown, so as to impress the audio-frequency signal between the system and earth, the transmitting apparatus being located in a substation.

It will be seen that it is necessary to insert a small choke in the substation earth connection, to avoid the transmitter being short-circuited at the point of transmission. The size of this choke is determined by the signal frequency selected. The higher the frequency, the lower can be the inductance of the choke.

In order that the power of the transmitter may be kept as low as possible, frequencies as high as 4 000 cycles are sometimes employed, and an emission voltage of anything from 10 to 60 volts.

* *Journal I.E.E.*, 1913, vol. 50, p. 240.

The reception relays can be connected either between neutral and earth or between phase and earth.

A variation of the method is illustrated in Fig. 2, in which the signal emission is effected between all three

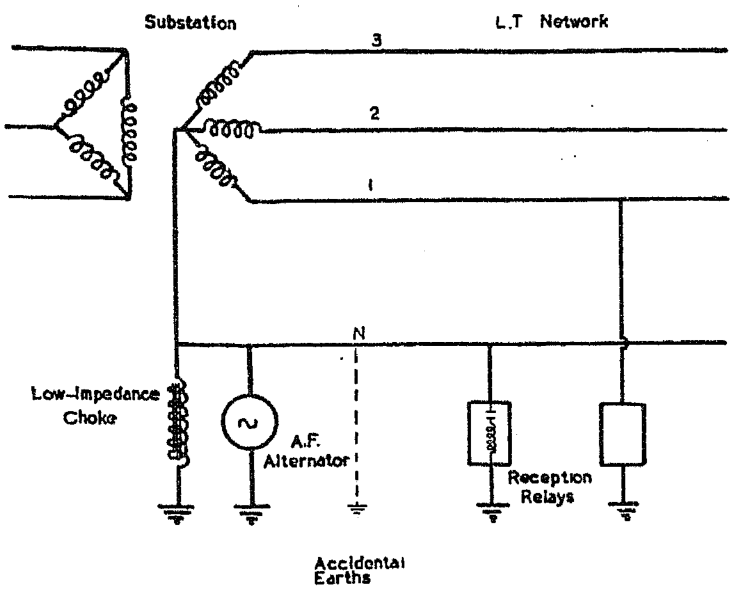

Fig. 1.—The principle of the " earth-return " system.

phases and earth through the intermediary of condensers, which prevent the load from short-circuiting through the signal generator.

Systems of this type are simple and low in first cost, but suffer from disabilities which have restricted their successful application. These are:—

(*a*) That although it is customary to earth a low-tension system at only one point, in the manner illustrated, it is in practice difficult to prevent accidental earths of low impedance developing in consumers' premises on the neutral side. Such earths may be caused by piercing a lead-covered cable, and the consumer himself never knows of them as his fuses do not blow. The existence of these

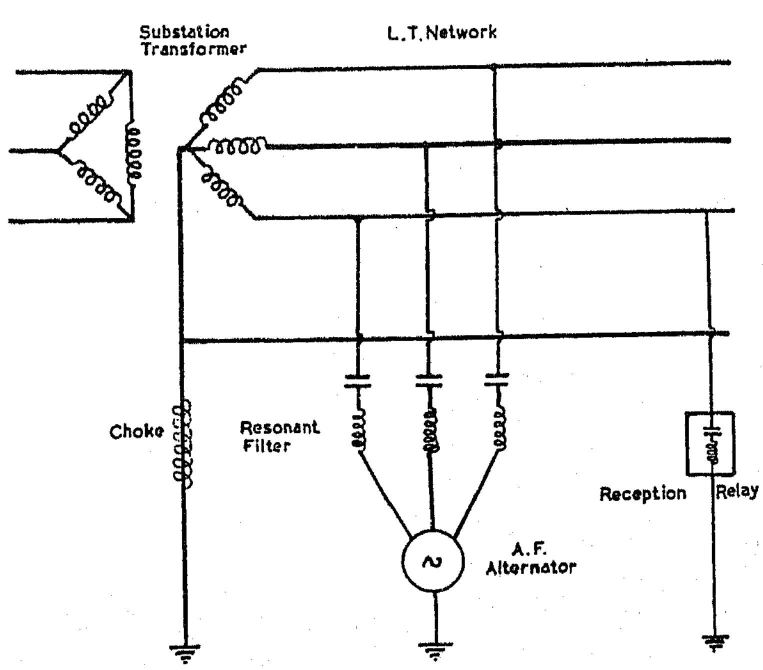

Fig. 2.—A variation of the " earth return " method.

earth faults can constitute a disabling feature of the method, since their existence may cause the signal voltage to fall away at points adjacent to the fault. It is unfortunate that as the network gets older, this difficulty tends to increase and may result in a progressive deterioration of performance. It has been argued that the sensitivity of systems of this type to earth faults is a beneficial feature, since it draws attention to their existence in a positive manner. The author feels, however, that supply engineers would not welcome the failure of street-lighting control as a means of indicating faults in the neutral, which in most cases they would prefer to forget, owing to the cost and difficulty of finding them.

(*b*) That in some districts where systems of this type are in use for public-lighting control, it has been found difficult to find a satisfactory earth connection in the lamp column.

The author had the opportunity recently of experimenting with the earth-return system on a large low-tension network of about 10 000 kW maximum demand, under conditions which, apart from the size of the network, were almost ideal.

A 6-kVA transmitter was installed to deliver at will signals at 300 or 500 cycles between the network and earth. The power of the generator was far greater than actually required.

These experiments gave results of considerable interest. They showed, first, that the effects of casual earth faults were not so severe on this particular network as the author had expected. Secondly, they showed that if the frequencies used are low enough, the signal voltages available at various points are quite consistent from day to day.

Thirdly, the difficulty of obtaining a satisfactory earth connection in a lamp column was again demonstrated, the cable leads not being continuously jointed.

Fourthly, what appears to be a further severe limitation of the earth-return system was discovered. With ample signal power in reserve, it was found impossible to obtain any measurable signal voltage in the most distant parts of the network, not more than $1\frac{1}{2}$ miles away. Raising the voltage of the transmitter raised correspondingly the voltage received within a half-mile radius of the point of transmission, but the voltage continued to fall away to nothing at the most distant points.

By interpolating the results obtained, the author demonstrated to his own satisfaction that the signal would have to be injected at a totally impracticable voltage if 1 volt only were to be available at the extremities of the system.

The cause of this voltage-drop appears to be that an ordinary distribution network, comprising distributors and consumers' wiring (the latter, it must be remembered, is not disconnected from the system neutral at any time) has a large capacitance to earth. This capacitance is much greater than that existing between phase and neutral.

When the signal is transmitted, this capacitance draws a large charging current at signal frequencies, which current, passing through the system and returning via earth, suffers a considerable voltage-drop due to the inherent reactance of the cables.

This effect would undoubtedly be more acute at the higher frequencies.

This experiment convinced the author that the earth-return method could not be applied from a single emitter on large low-tension networks.

The operation of the earth-return method is often

erratic, although it may be rendered satisfactory if the reception relay can be designed to operate equally well over a wide range of signal voltage, since the voltage it must receive must vary from day to day with the state of insulation of the network, and cannot be prophesied with any exactitude when the installation is planned.

On a large network where low-tension systems are not interconnected at either phase or neutral, a separate transmitter is required for each substation, but in certain circumstances the multiplicity of transmitters can be reduced by coupling adjacent low-tension networks by condensers which will transmit the signal from one system to another.

The Star Neutral Method

This method, which again can be applied only to low-tension systems, is illustrated in Fig. 3; it overcomes many of the disabilities of the earth-return system at the expense of a somewhat more expensive transmitter.

In this system the signal is injected between the star point of the low-tension transformer windings and neutral, and thus the signal circuit is made between phase and neutral instead of between neutral and earth. This system is not affected in any way by earth faults.

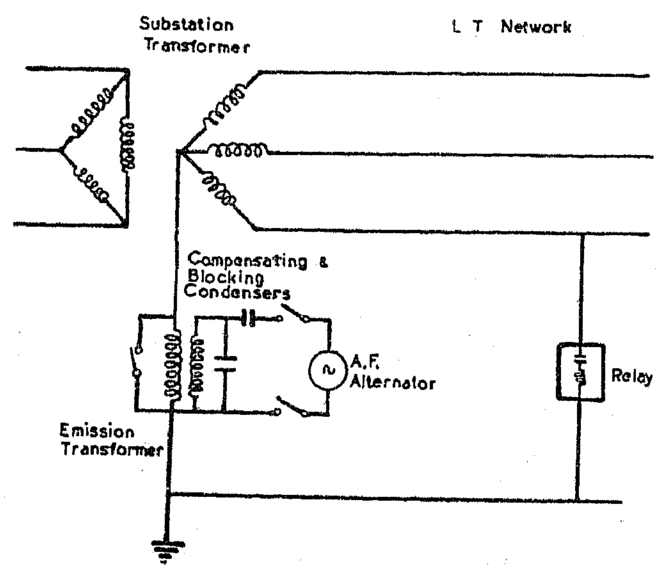

Fig. 3.—The "starpoint-neutral" method.

The audio-frequency signal current is generated by a small alternator providing about 1 kVA output at 400 cycles. The output of the machine is fed into a small transformer on which the secondary winding is permanently in series with the neutral and designed to carry safely any out-of-balance or fault currents which may occur.

At normal times the primary winding of this transformer is short-circuited by a contactor.

As in the case of the earth-return method, the complete transmitter may be operated either by push-button or time switch.

The reception relays, which are connected between phase and neutral, may be of the "sustained signal" type described in Section (5).

This method, although extremely reliable in practice, suffers from the disability that it cannot be used on networks fed by a number of different substations without the use of neutral chokes in substations other than that containing the transmitter.

D.C. Bias Method

As an alternative to the use of a superimposed audio-frequency signal, the use of a direct-current signal has frequently been suggested.

In 1917 Reeves described* a method of control, illustrated in Fig. 5, in which a d.c. signal was applied by means of a battery between the network and earth. With the aid of a reversing switch, polarized relays could be caused to operate "On" or "Off."

An improvement of this method is shown in Fig. 4.

This method was originally proposed on the Continent some years ago and is now being practised.

A small 12-volt accumulator of the automobile type, which can sustain severe duty for short periods, can be connected across a low resistance placed in series with the neutral of the system. With the aid of a manually operated or electrically operated change-over switch, a positive or negative bias can be impressed at will between the three phases and neutral, and can operate polarized relays connected between phase and neutral.

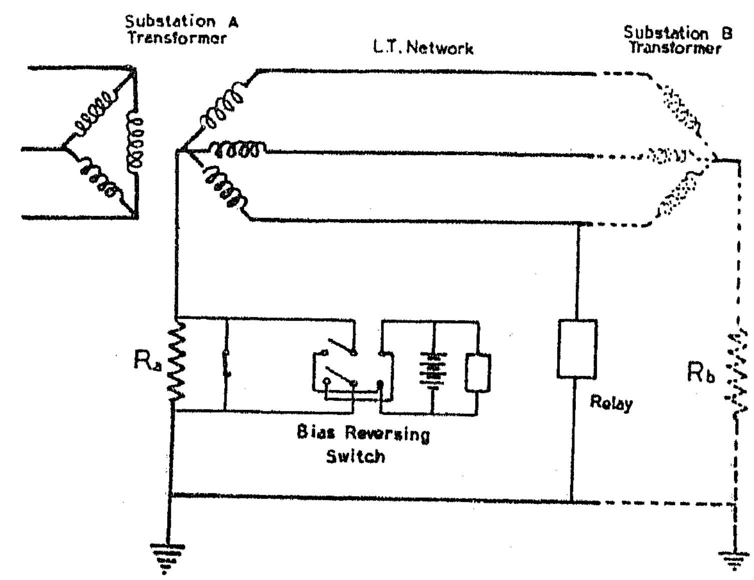

Fig. 4.—A practicable application of the d.c. bias method.

This system has the merit of being extremely cheap and simple to install at the transmitting end, as the transmitter need only consist of an accumulator, a trickle charger, a contactor for reversing the polarity, and a short-circuiting contactor for cutting the line resistance out of a circuit at normal times.

There is no doubt that, as in the case of the star-point neutral method, this system also is far superior to the earth-return technique and can probably be applied quite successfully to isolated low-tension networks for the control of public lighting. The method has, however, some limitations which will have to be overcome before the system can be generally adopted:—

(*a*) Referring again to Fig. 4, it can be seen that if two low-tension substations are feeding in parallel a common low-tension system, the d.c. bias cannot be applied in one substation, as the bias would be short-circuited by the other substation.

The propagation of the bias is solely dependent upon the ohmic resistance of the system and the load, plus any effects which self-inductance may have at the beginning and end of the bias signal.

* *General Electric Review*, 1917, vol. 20, p. 884.

This being so, it is very difficult to see how the bias method could be applied to any network fed from more than one substation, unless the substations are so far apart that the bias voltage transmitted from Substation A has fallen to zero at the terminals of Substation B, solely by reason of its dissipation through phase to neutral load.

If this is so, then separate transmitters, operating independently, could be placed one in each substation.

It is, however, quite evident that if the substations are close together, a resistance R_b must be inserted in the neutral lead in Substation B, and that this resistance must be put into circuit simultaneously with the injection of the bias. This could not be performed without pilot lines.

(*b*) Some difficulty may be experienced in avoiding false operation of relays occasioned by stray bias which the system may momentarily receive from transient causes, such as faults and the discharge of static condensers, for if relays are to be designed for operation on a single impulse they cannot discriminate between a deliberate one and an accidental one.

(*c*) No economical method has yet been devised of providing a number of different selective operations on the bias system, which prima facie can only provide two main discriminations by polarity reversal, one for " On " and one for " Off."

If further discriminations are required, then a time element must be introduced, and, in combination with changing polarity, discrimination is effected by impulsing.

Impulsing as such is well known and well tried, but it is hard to envisage a reception relay suitable, say, for water-heating control, capable of discriminatory operation by impulse, and at the same time combining absolute freedom from out-of-sequence derangement with a reasonably low cost.

The author's principal objection to all localized systems is the fact that they *are* localized, and it has always appeared to him that the true merit of centralized control is lost unless control is effected from an attended point.

Localized systems represent at best a trend towards centralization, but they do not represent centralization itself, and, except in very small networks or networks where a separate pilot exists to each substation, they do not always offer a sufficient measure of advantage over time-switch control to justify their adoption.

(4) COLLECTIVE CONTROL BY SIGNALS FROM THE CENTRAL STATION—THE RIPPLE SYSTEM

The fullest advantage can only be taken of the ripple control principle if a central ripple transmitter, located in the generating or bulk-supply station, can be designed to cover the entire network fed at high tension from that point.

As the latest and most impressive developments of centralized control have been in effecting control directly from the central station, the author will discuss in detail the technique employed.

It is evident that the basic problems in such systems are entirely different from those of the localized or low-tension systems already described.

The distinction is that a ripple transmitted from the generating station must traverse the high-tension feeders and pass through substations before operating the reception relays.

It can, first, be shown that no prima facie difficulty exists in using an a.c. network comprising the usual primary high-tension distribution system for the conveyance of an a.c. signal of a frequency different from that of the load, and, further, that if such a signal has a frequency substantially higher than that of the load itself the effect on the consumer's voltage at the moment of signalling is inappreciable even though the signal voltage may be considerable.

Fig. 5 illustrates the application of an audio-frequency signal with a frequency of 500 cycles and 1 000 volts (r.m.s.) superimposed on an 11 000-volt 50-cycle supply. It can be seen graphically, and easily verified by calculation, that even if so considerable a signal voltage is superimposed on the load the resultant increase in the r.m.s. voltages at 50 cycles is inappreciable.

The thick line illustrates the resultant of the two a.c. voltages, and would be reproduced, for example, by a cathode-ray oscillograph connected at the moment of signalling.

It can be seen that the order of magnitude of the wave-form deformation is not substantially greater than the deformation which occurs momentarily on any network owing to accidental or transient disturbances.

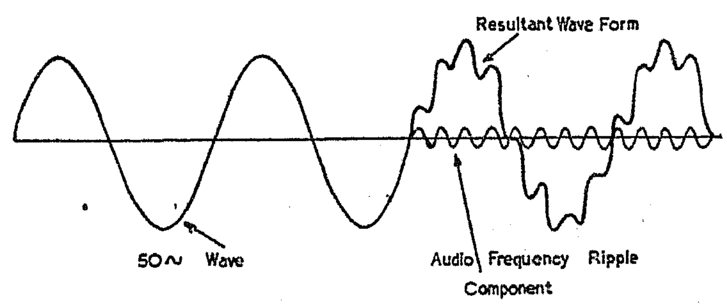

Fig. 5.—The effect of a signal ripple on the system wave-form.

From the point of view of the reception relay, the only distinctive feature of a deliberate wave-form deformation or " ripple " is that the deforming component is sinusoidal, monotonic, and may persist for a period of seconds.

Although physically the two a.c. voltages combine in this manner, yet the propagation of the ripple can be considered distinctly from the propagation of the load, and, from the point of view of calculation, the load can be neglected and the distribution system regarded as existing solely for the purpose of propagating the ripple.

This being so, it is evident that if a 3-phase audio-frequency ripple is superimposed on a 3-phase high-tension system, the ripple will be transformed by the substation in the same voltage ratio as the load. Thus, a ripple if injected at a generating station must traverse the high-tension feeders, pass through the substations, and appear as a phase-to-phase or phase-to-neutral voltage on a 4-wire system in precisely the manner of the load itself.

Since the ripple utilizes the same circuit as the load, it must appear at the terminals of, and be absorbed by, every piece of current-consuming apparatus on the system.

In considering the propagation of the signal, it must be remembered that although the ripple traverses the same circuit as the load, it does not suffer the same proportionate losses in transit, as there are a variety of effects which tend to absorb the audio-frequency ripple signal to a greater extent than they absorb the load, since the effects of reactance and capacitance are increased at the higher frequency.

Although this summary does not disclose any difficulty in the propagation of the ripple from the generating station to the consumer's terminals, there are certain factors which must be taken into account when the employment of the principle is being considered on extensive networks, particularly with long overhead lines.

On urban networks, where underground cables are used and geographical distances are small, it is never necessary to consider the effects of attenuation or reflection, but where a ripple at, say, 500 to 600 cycles is being transmitted over overhead lines of considerable length, a phenomenon occurs which is similar to the Ferranti effect.

It is well known that the terminal voltage of a long high-tension line under conditions of light load or open-circuit is frequently in excess of the initial voltage applied.

The phenomenon is experienced most acutely when the length of the line is of the order of a quarter of a wavelength.

This length (in miles) is determined by dividing the velocity of propagation of the wave by the frequency, which gives the whole wavelength, i.e. the linear distance between corresponding points on the voltage cycle.

At load frequencies of 50 cycles this distance is about 3 600 miles on overhead lines, and the quarter wavelength occupies 900 miles. This distance being considerable, these effects do not attain their maximum at load frequencies, since the correct combination of circumstances rarely exists.

At ripple frequencies of 500 or 600 cycles the effect may be more pronounced, since the quarter wavelength occupies only about 80 miles on an overhead line where the velocity of propagation is about 180 000 miles per second.

In an underground cable the velocity of propagation is reduced to about 80 000 miles per second, and as a result the quarter wavelength occupies only 30 to 40 miles at ripple frequencies.

The effect of this is that, due to the effects of reflection, the ripple voltage may exhibit fluctuations at the point of reception, and this possibility has to be borne in mind in planning centralized ripple control schemes and designing reception relays.

In ordinary practice, however, no difficulty results since the phenomenon, once appreciated, can be guarded against.

It has, however, a considerable bearing on the ripple frequencies which are employed. On the one hand, it is desirable to keep these frequencies as high as possible, since the amount of ripple power absorbed by the system decreases as the frequency rises.

On the other hand it is desirable to keep ripple frequencies sufficiently low to avoid attenuation and reflection effects.

These and other conditions have led to the employment of frequencies between 300 and 800 cycles.

The choice of frequencies is further limited by the necessity of avoiding odd harmonics of 50 cycles.

A centralized ripple controller employed for twelve different purposes must transmit twelve different frequencies at will, a typical set of frequencies being:

370	Street lights " On."
400	Midnight lamps " Off."
420	Remaining lamps " Off."
480	Water heaters " On."
510	Water heaters " Off."
570	Shop-window lighting " On."
600	Shop-window lighting " Off."
630	Off-peak space heating " On."
680	Off-peak space heating " Off."
720	Air-raid alarm.
770	Spare.
830	Spare.

It will facilitate appreciation of the methods which have been successfully adopted to realize these principles

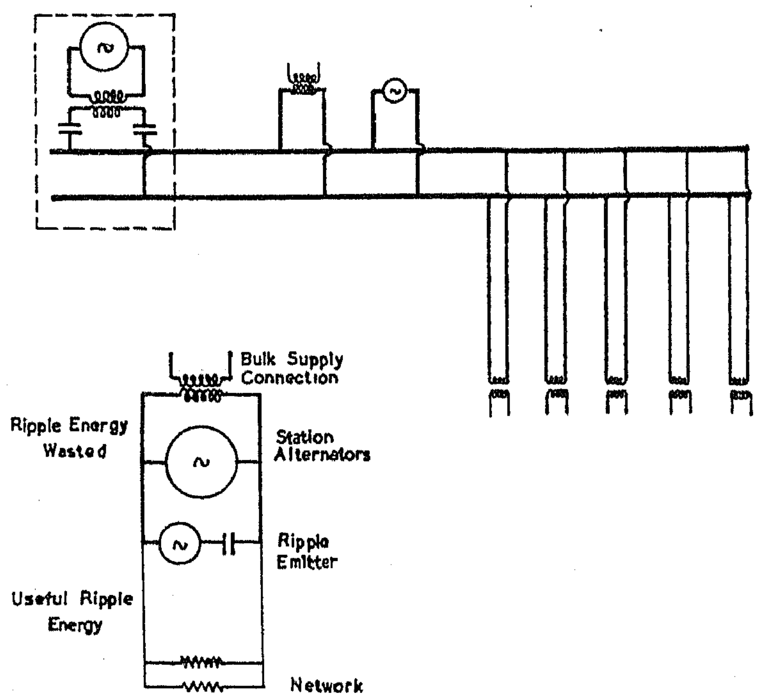

Fig. 6.—The "parallel" method of ripple emission.

if the elements of the matter are examined in their simplest form.

There are two methods by which the 3-phase ripple may be impressed on to a high-tension system at the central station.

Fig. 6 illustrates the simplest of these, which is known as the "parallel method."

The Parallel Method of Ripple Emission

Fig. 6 illustrates a typical supply system consisting of a high-tension distribution system fed from station alternators and reinforced by a connection from the grid system.

In this method the ripple is generated by means of a 3-phase audio-frequency alternator, and is fed directly on to the station busbars by the intermediary of a resonant filter which admits the ripple to the network but prevents the 50-cycle voltage from short-circuiting through the ripple generator. This apparently simple method is open to serious objections, the principal being as follows.

The energy of the ripple when injected on to the busbars is clearly dissipated in two directions, through the alternators and grid transformers supplying the system or, as intended, in the distribution system and consuming circuits. As between these two the ripple primarily chooses the path of lowest impedance, which in every case is the source of supply. As a result a very large proportion of the ripple energy is wasted.

Furthermore, the ripple is in this method being applied across the terminals of the bulk supply or grid transformers, and may propagate backwards into the bulk supply system and appear on the busbars of another undertaking. The actual proportion of the energy dissipated forwards and backwards can be calculated, as it depends primarily on the size and reactance of the bulk-supply transformers and generators.

On a network of, say, 20 000 kVA maximum demand the ripple generator output might have to be as large as 200 kVA and would necessitate an expensive and rather unwieldy machine.

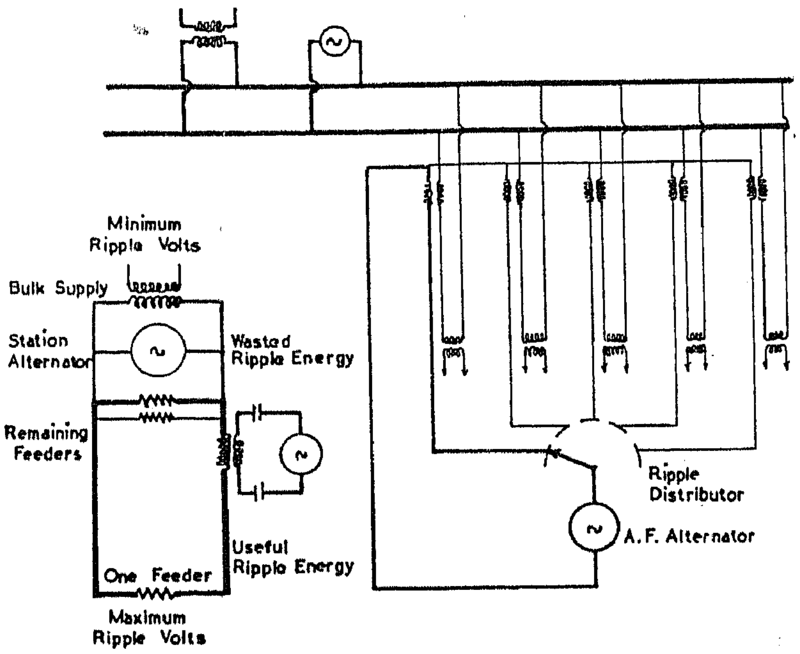

Fig. 7.—The principle of the "series" emission method.

A further practical difficulty in this method is that the ripple is being injected at a point where the short-circuit kVA is at its highest, and the filter condensers must therefore be protected by a circuit-breaker.

Despite these objections, the parallel-emission method is by no means entirely impracticable and has been employed successfully in Hollywood, California,* and at Potsdam, Germany.

Series Emission Method

This method is illustrated in Fig. 7.

It is clear that the short-circuiting effect of the source of supply can be turned to advantage if the ripple is injected in series with the load instead of in parallel with it.

In this method the ripple current which traverses the source of supply is equal to the current traversing the network, since the source of supply, the ripple emitter and the network, are in effect in series.

It has already been shown that the impedance of the source of supply is lower than that of the network. As a result the ripple voltage applied is dissipated across that part of the circuit which has the higher impedance, namely the distribution system, and only a small voltage appears across the source of supply.

It was realized that this method offered as a further advantage that by the use of ripple emission transformers connected in series with the feeders in the manner shown, the ripple could be injected on to the outgoing feeders sequentially rather than simultaneously, and that by this means the amount of ripple power required would be reduced by taking a "number of bites at the cherry." Since the network as a whole consists of a number of parallel circuits between the busbars, comprising feeders and alternators, the ripple injected into one feeder utilizes all these remaining circuits in parallel in its return across the busbars.

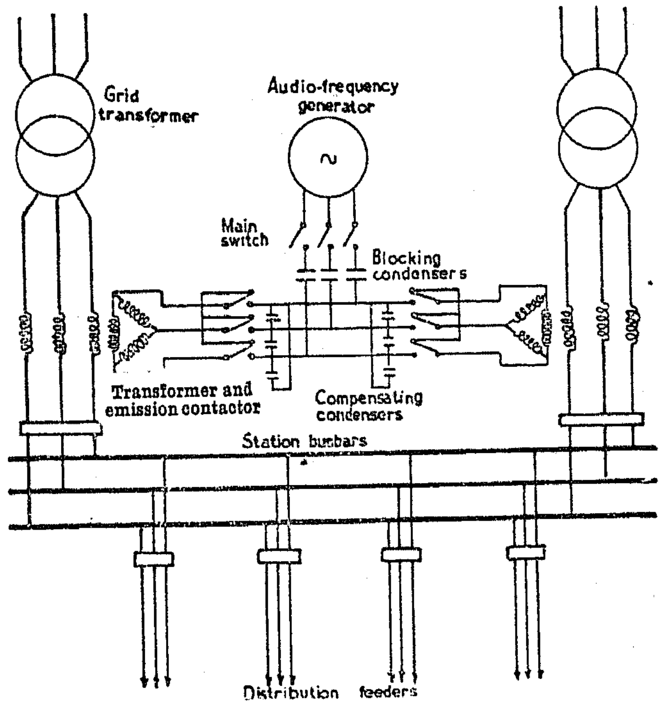

Fig. 8.—Application of "series emission" to a small system.

Now it is clear that although the impedance of the source of supply is low, this impedance, paralleled with that of the remaining feeders, is negligible. Therefore, a ripple emitted in series on one feeder is dissipated almost entirely in that feeder, and does not affect any other feeders *unless they are interconnected in the network.*

It is necessary, of course, that if two or more feeders are interconnected externally to the station, the ripple emission transformers on these feeders should be energized simultaneously, since interconnected feeders are in this sense only one feeder.

Fig. 8 illustrates how the series emission method may be applied to a small system taking a bulk supply.

The following advantages result from the adoption of the series emission method:—

(*a*) As already explained, the ripple power required is small.

(*b*) The ripple is propagated only towards the consuming end of the system and cannot interfere with an adjacent undertaking fed from a common bulk-supply system.

(*c*) Since the energy required to ripple the load of a given feeder can never exceed a value which is related to

* *Electrical World*, 1935, vol. 105, p. 2886.

the size of the feeder itself, and since as time progresses and the network expands the source of supply becomes larger and its impedance lower, it follows that the power required from the ripple generator tends to get lower as times goes on, and an equipment designed to be adequate for a network at a given stage of development will always be adequate for that network, unless the scheme of distribution is radically changed.

(*d*) As a network develops and more and more feeders are added to the busbars, the ripple transmitter can be extended to serve new feeders without dérangement.

(*e*) The ripple injection is effected into the system at a point where apparatus involved is protected from short-circuit damage by the existence of the feeder switchgear itself.

It may now be said that ripple control by the series emission method is established engineering practice, and the author will now describe in outline the equipment which is being used to realize the principles described.

Fig. 9 illustrates the main circuit arrangement for ripple emission on to a 3-phase network. The ripple is injected by means of transformers in which the secondary windings are permanently connected in series with the feeders, the primary windings being delta-connected. Each emission transformer is normally constructed in three separate single-phase units.

The primary windings of each emission transformer are energized through a double-throw contactor which during normal times short-circuits the primary winding and only connects it to the ripple supply at the moment of signalling.

At normal times, therefore, the 50-cycle voltage-drop across the transformer is negligible.

At the moment of emission, when the primary winding is receiving ripple supply, a voltage-drop of about 1 % of the network voltage occurs across the high-tension windings.

These windings have to be very robustly constructed since they must withstand not only the maximum feeder load but also any stresses due to the maximum available short-circuit kVA.

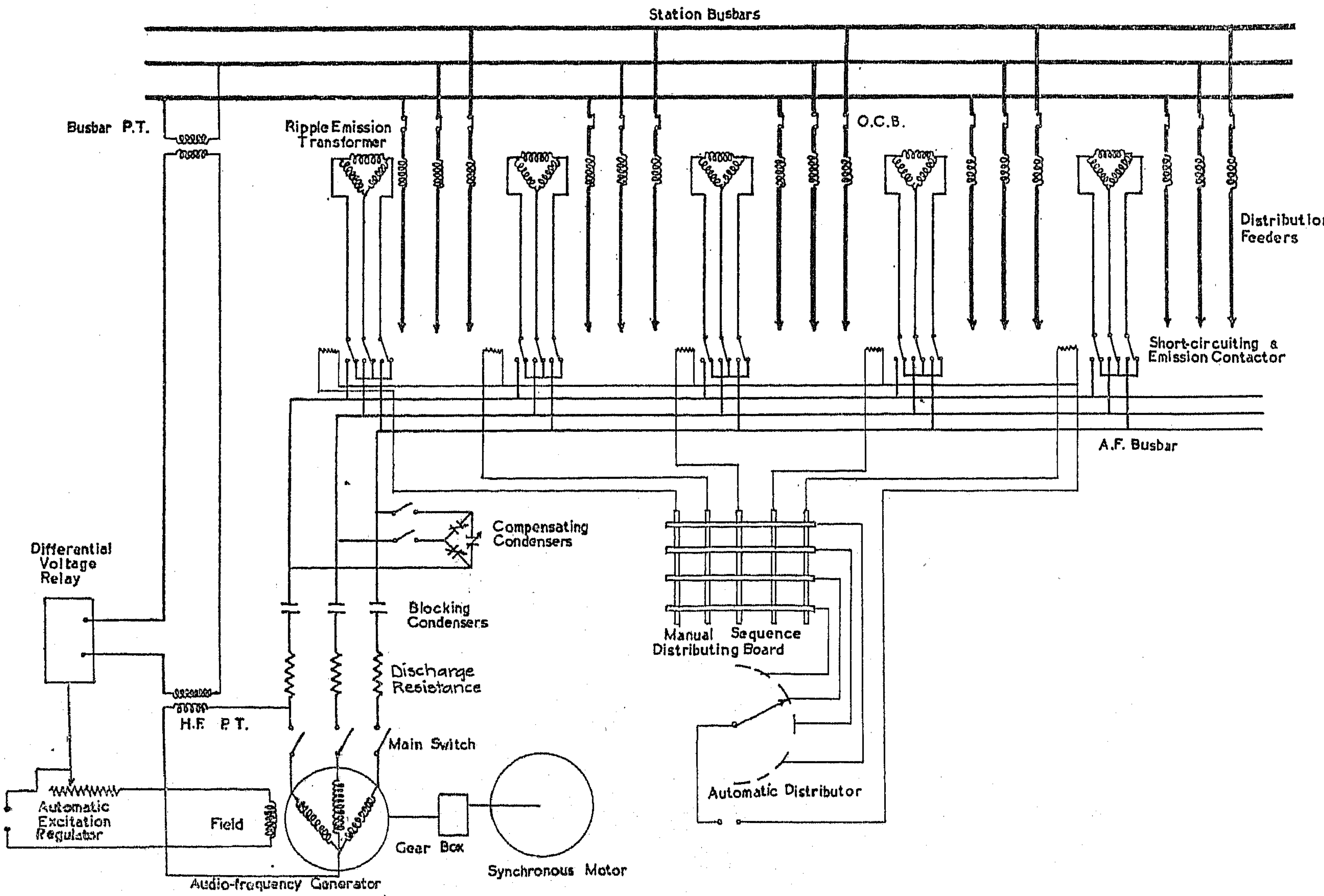

Fig. 9.—Series ripple emission on feeder-by-feeder principle.

It is also necessary to provide that, if during an emission a short-circuit should occur on the feeders, no harm can result to the ripple generator or allied equipment.

To effect this, the transformer is so designed that the iron reaches saturation at such a point that not more than 2 000–3 000 amperes can circulate in the primary circuit.

This leads to the necessity of providing a gap in the iron circuit of the transformer, which in turn results in an increase in the magnetizing current in the primary circuit during transmission. This magnetizing current has to be compensated by condensers which are delta-connected across the input side. The value of these condensers has to be adjusted for each emission frequency, since the

compensating capacitance required depends on the frequency.

On the generator side of the compensating condensers are connected blocking condensers which serve to prevent the ingress of the 50-cycle voltage component into the alternator itself.

Various protective and stabilizing devices have to be installed in the circuit, but it is outside the scope of this paper to describe their construction or function.

The alternator, which may have an output of 30–75 kVA at ripple frequencies, is driven either by a synchronous motor through the intermediary of a mechanical change-speed gear box or by a d.c. motor.

The choice of drives depends largely on the number of ripple frequencies required, and also on the constancy of the 50-cycle frequency.

Where a large number of ripple frequencies are required, it is general practice to use a d.c. motor, the speed of which has to be regulated automatically to within very close limits.

Since the ripple emission is injected sequentially on to the feeders, a rotary distributor is provided which, by closing the emission contactors in a prearranged sequence, admits the output of the ripple generator on to the feeders in accordance with the state of interconnection of the network, it being necessary to make simultaneous emissions on to all feeders which are mutually connected below the station busbars.

In order to ensure that, so far as possible, the reception relays always receive a ripple of constant amplitude, it has been necessary to develop special methods of controlling the output voltage of the ripple generator.

The measurement of the ripple voltage on the feeder is effected by means of a special voltmeter which measures the difference between the voltage injected by the emission transformers and the voltage which appears across the busbars occasioned by the finite but small impedance of the return circuit.

This differential voltmeter operates, through the intermediary of relays, a servo-motor-driven rheostat connected in series with the excitation circuit of the ripple alternator.

By this method the uniformity of ripple voltage is assured, even though the network load may be varying widely during the progress of the emission.

The ripple emitter installed in the generating station of the Maidstone Corporation is operated from a control panel normally located in the station control room, which comprises the various push-buttons, pilot lamps, protective relays, and other apparatus.

It is normal to design the whole equipment for fully automatic operation so that a single push-button can select the emission frequency required, start the generator, make all the correct circuit arrangements for the selected frequency, and then transfer the output of the generator to the various feeders in accordance with a sequence of operations prescribed by the state of interconnection of the network at the moment.

In order to provide that the emissions are injected into the feeders in the correct sequence, a plug and jack board is generally installed on the control panel, by the aid of which a control attendant can arrange for given feeders to be rippled simultaneously if they are running as a solid ring, and for the ripple emission to be isolated from a feeder which may be out of service for repair.

Factors Governing the Design and Cost of Ripple Control Transmitters

From the foregoing description it will be appreciated that both the cost and the method of application of a centralized ripple transmitter varies from one installation to the next, and that although the principle can be applied to a very high proportion of networks in this country there are some factors which restrict the application of the system in special cases.

(1) Network Maximum Demand.

The size of a network as measured by kilowatts of maximum demand is never *per se* a factor which can limit the application of the system.

(2) H.T. Distribution Voltage.

In Great Britain secondary distribution voltages in excess of 33 kV are not used, and ripple emission transformers are designed for all voltages up to this figure.

(3) Stages of Transformation through which the Ripple must pass.

It is relatively seldom that between a main distribution centre and the consumer more than two stages of transformation are interposed, e.g. 33/6·6 kV/400/230 V. More commonly there is only one.

While, given adequate power, there is no theoretical limit to the number of transformations to which the ripple can be subjected, three may be taken as the practical maximum.

For example, several municipal undertakings in this country having an urban distribution system at 6·6 kV are at the same time supplying extensive rural areas from the same busbars by means of 11- or 33-kV feeders. This often implies three stages of transformation, e.g. 6·6/33 kV, 33/6·6 kV, and 6·6 kV/400/230 V.

Provided that the reactance of the transformers is low, the application of ripple systems presents no great difficulty. If, however, the reactance of the transformers is high, the large ripple power required may be a limiting factor.

(4) Size of Feeders.

Emission transformers are more generally located in outgoing feeders whose rating rarely exceeds 350 amperes.

In some stations where group feeders are employed, generally with reactors to distribute energy from the main station busbar to sub-distribution bars of the same voltage, it is necessary to provide ripple emission transformers up to 1 000 amperes capacity at 11 kV. Such transformers can readily be designed and it can be said that feeder sizes never constitute a limiting factor in the application of the system.

(5) Network Interconnection.

It is inherent in the series emission method that the ripple is transmitted to the system "feeder by feeder" or "group by group," a group of feeders being defined as the largest number of feeders which may ever be interconnected externally to the station either at high or low tension.

In the majority of cases where networks are fed from a single distribution centre the tendency is to limit the number of interconnected feeders to 3 or 4. In such circumstances the ripple transmitter must be sufficiently powerful to transmit on 4 feeders at the same instant.

Unless the network is very large and the impedance between the busbars correspondingly low, the application of the series emission method becomes difficult where more than 6 feeders are interconnected.

In planning an installation it is always necessary to assume that in times of fault or emergency the network may have to be interconnected to a greater extent than in normal running. Corresponding provision must be made for this in the design of the equipment.

It is difficult to apply ripple control to any network fed from two primary points of distribution. Fortunately, however, such networks are rare in this country, and in any event are generally so large that it is more practicable to place the ripple emitters lower down on the system. As an illustration, an undertaking may have two power stations, one distributing at 6·6 kV, the other at 33 kV, the 33-kV system reinforcing the 6·6-kV system at primary substations. It is impossible to apply a ripple emitter in either of the two power stations, and it is therefore necessary to provide separate emitters in each of the primary substations.

Since, however, each of these primary substations may be as large as a medium-sized undertaking, this method is the best from all points of view, and the cost of the transmitter per kilowatt of network maximum demand is not higher than on a smaller self-contained network.

(6) Geographical Distances.

In general, geographical distances are not a limiting factor, although extensive networks where the furthest consumer is more than 50 cable miles from the transmitter require special consideration.

(7) Accommodation of Transmitter.

In very few cases has any difficulty been experienced in accommodating the transmission equipment in a generating or bulk-supply station.

The accommodation of the emission transformers connected directly in series with the feeders sometimes necessitates the rearrangement of a cable basement, and the author in the course of his researches has only found one generating station in this country in which there is literally no space whatever for the accommodation of the emission transformers, and where, in consequence, the system cannot be applied.

The author wishes, however, to draw the attention of supply authorities engaged in building or reconstruction of primary substations to the fact that it is very easy to provide space for the future installation of ripple emission transformers by a suitable arrangement of cable basements or feeder trenches, and that if such forethought is exercised it will be well repaid if, as the author believes, the adoption of ripple control becomes universal in the next decade.

Ripple Control Installations in Operation

The technique outlined has been well known and widely practised for the last 10 years in many countries, although its adoption in Great Britain has only recently commenced.

Immediately preceding and just after the War, ripple installations embodying the principle of series emission were effected in England, notably at Leatherhead, Dartford, and the Isle of Man.

These installations embodied the principle in its simplest form, but were not capable at that time of adoption, without radical improvement, on large networks.

In about 1920, a serious study of the problem was initiated in France, and in 1928 the first of a series of large installations was put into service in Paris.

In the 10 years which followed, the series ripple control system was adopted throughout the entire Paris region, and there are now in operation 28 installations which provide a 9-frequency ripple service over an area approaching 1 000 square miles.

These installations embody the most advanced technique and give entirely satisfactory service in the control of public lighting, multiple-tariff metering, off-peak loads, air-raid alarms, and other purposes, one undertaking alone having more than 15 000 relays in service.

During last year the installations in the Paris area transmitted about 50 000 ripple signals, with a wholly negligible proportion of relay failures.

Other installations are in service in many provincial centres in France, Belgium, and elsewhere.

In the United States there has been some development, and ripple installations are operating at Springfield, Idaho Falls, and Hollywood.

These installations are generally much less advanced in conception and execution than the latest European practice.

In Great Britain the first large installation was put into service last summer at Maidstone, where a transmitter in the central station is providing four frequencies for the control of public lighting and off-peak heating loads on an extensive a.c. system and a smaller 3-wire d.c. network. This installation is giving completely satisfactory service.

Other installations are in course of installation in this country, and many more will follow as the capabilities of the method become more widely appreciated.

The author has outlined such limitations as exist and which, being of a fundamental nature, are difficult to overcome, but in general the successful application of the principle depends not upon limitations of the principle but on technical skill in execution.

(5) Ripple Reception Relays

Relays used for the reception of ripple signals can be divided into two categories, viz:—

(*a*) Those which are operated by a single ripple impulse of short duration.

(*b*) Those which are operated by a ripple signal sustained for a period of seconds, and which may be regarded as audio-frequency motors.

All ripple relays embody the same principle, i.e. the separation of the ripple component from the 50-cycle voltage by means of a resonant filter. If, for example, a relay is designed to receive ripple signals of 620 and 670 cycles, the values of the capacitance and inductance

are so selected that, in combination, their resonance peak is mid-way between these operating frequencies.

The mechanical motion of the relay is utilized to operate either a mercury switch or a small air-break switch directly in circuit with the controlled load.

Impulse Relays.

For use in conjunction with localized transmission systems relays of the impulse type are sometimes employed. With this type of relay the ripple impulses are generally of the same frequency for both " On " and " Off " operations, the first impulse switching the relays on and the next one switching them off.

This type of relay is not always satisfactory, for the following reasons:—

(*a*) Since this system of operation is cyclic, i.e. the same ripple frequency is used for on and off operations, it follows that a breakdown or derangement of the emitter may leave some relays in the " On " position and some in the " Off." It is subsequently impossible to bring the relays into step, and they have to be re-set by hand.

(*b*) Any impulse type relay suffers from the mechanical limitation that it absorbs ripple power for a very short space of time, perhaps only one-tenth of a second, or less. As a result, the output of mechanical power available for the operation of the load contact is very limited, and the device must necessarily be of a delicate nature incapable of breaking heavy currents without an amplifying contactor.

(*c*) Such relays are apt to be operated falsely by transient high-frequency disturbances in the system occasioned by faults or the breaking of heavy currents in the vicinity.

It is well known that under fault conditions a variable-frequency deformation may traverse the whole system, and if it should happen that in the course of its variations the frequency should pass through the frequency to which the relays are set, a false operation may result.

These difficulties are now widely accepted, and the relays most widely used on ripple control systems are of the sustained-signal or motor types.

Sustained-Signal or Motor-Type Relays.

In distinction to the instantaneous relays described in the foregoing, it is now general practice to use a relay which requires that the ripple should be maintained for a period of seconds at constant frequency.

The basic principle of such a relay is illustrated in Fig. 10. Electrically, the relay mechanism comprises a condenser which is in series with an electromagnet of such inductance that with the condenser it constitutes a resonant filter as earlier described.

The incoming ripple is converted into an alternating flux at the poles of the electromagnet. This electromagnet has two armatures, each of which is a reed tuned to resonate mechanically at a frequency corresponding to one of the two ripple frequencies used. Thus one reed resonates at the " Off " frequency and the other at the " On."

Attached to each reed is a flexible steel pawl, the top of which rests on a toothed fibre wheel.

When an " On " ripple is received by the relay, the " On " reed vibrates and drives the fibre wheel round by a pawl-and-ratchet action, the rotation of the fibre wheel tilting a mercury contact through the intermediary of reduction gearing of the meter type. When the " Off " emission is received the second reed commences to vibrate, the direction of rotation is reversed, and the mercury switch is tilted in the other direction.

Although Fig. 10 illustrates the principle of such relays, it is in practice necessary to employ a somewhat more complicated construction.

In order to ensure that transient disturbances shall not cause the relay to creep, a centrifugal clutch is frequently fitted on the ratchet-wheel spindle; this will only connect the ratchet wheel with the mercury contact rocker when the speed of rotation of the ratchet spindle is comparable with the synchronous speed due to the ripple frequency.

It is also usual to provide an arrangement of cams whereby, when the relay has attained the limit of its travel either " On " or " Off," the operating pawl is

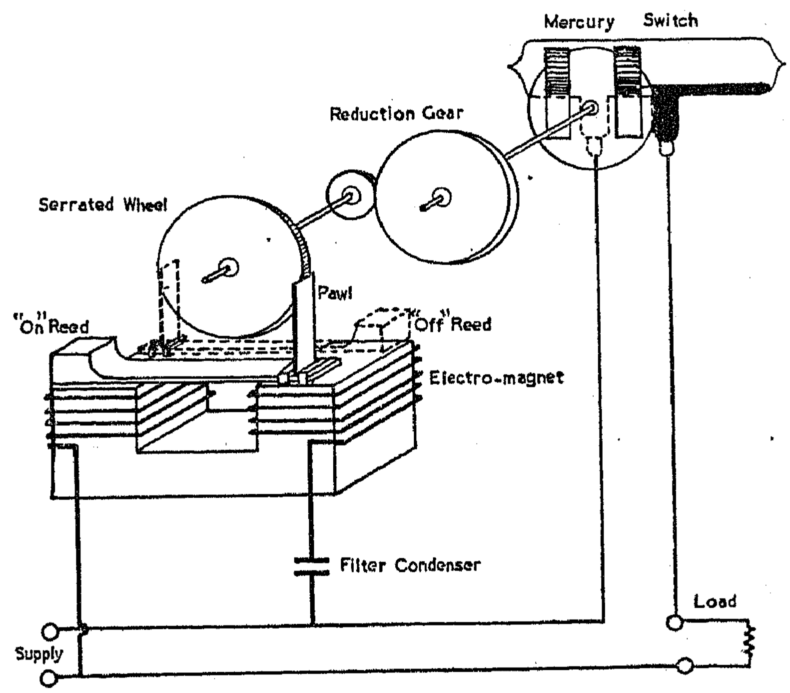

Fig. 10.—The principle of a typical ripple control relay.

mechanically disengaged from the ratchet wheel and the non-operating pawl is engaged in readiness for the opposite operation.

Relays of this type are now very widely used and give extremely reliable results.

Other types of relay in successful operation embody the use of rectifiers which convert the incoming ripple component into direct current, which operates a bimetal relay which in turn operates a contactor.

(6) THE PRACTICAL APPLICATION OF RIPPLE CONTROL

(i) Public Lighting Control.

The centralized switching of street lighting is one of the most important services which ripple control can render, and is a field in which great success has been achieved.

Earlier in this paper the author has discussed alternative methods of controlling public lighting by means of separate cable networks, and it has been pointed out that where such networks exist ripple control can generally effect neither improvement nor economy in service.

The installation of separate public-lighting cables is, however, the exception and not the rule, and the greater part of the public lighting in this country is controlled by means of separate time-switches, one switch controlling each standard or each group of standards. It has already been admitted that the time-switch is, *per se*, a reliable and well-proved device, but despite this ripple control is fast replacing the time-switch in many towns and cities in Europe.

The merits of ripple control are partly ones of economy and partly ones of convenience, and may be summarized as follows:—

(*a*) It has been observed that circumstances frequently arise where the control of public lighting should not be determined by time alone. In the case of fog, for example, the time routine must be broken, and to effect this either ripple control or photo-electric control constitutes a satisfactory solution.

In the event of war a centralized control system alone can darken the streets in a matter of seconds. This aspect of the matter is discussed more fully elsewhere in this paper.

(*b*) A ripple relay only operates mechanically twice a day, and in consequence is not in any degree subject to mechanical wear. This is an extremely important advantage of the system, since the annual cost of a relay or time-switch is principally determined by its effective life.

(*c*) The absence of wear results in a complete abolition of maintenance, and it is normal practice for ripple control relays to be permanently sealed when installed, and left without any routine maintenance at all.

(*d*) Apart from the abolition of mechanical maintenance, a ripple relay abolishes the necessity for winding and setting. In this connection it is sometimes argued that since public lamps have in any event to be inspected periodically for the cleaning of reflectors, a man might just as well pause to wind a time-switch, as he has to be on the spot, and that this winding and setting service costs nothing. This always appears to the author most fallacious, since a lamp cleaner can obviously clean more lamps per day if he has not to wind a time-switch as well.

(*e*) As to reliability, the experience of public-lighting control by ripple signals has provided most impressive data.

A careful record covering many millions of relay operations on a network where 15 000 relays are installed has shown that failures in operation from all causes do not, on an average, exceed 2 per 100 000 operations. This is equivalent to an operating efficiency of 99·998 %. Despite the mechanical excellence of the modern time-switch it is very doubtful whether the failures of operation from all causes attain so low a figure as this. In practice these failures appear to run between 10 and 20 per 100 000, i.e. 5 to 10 times as many as those which occur on a well-designed ripple control system.

In areas where side-street lighting is switched off at midnight and only the main-street lighting maintained until morning, it is necessary to provide an extra control frequency.

With three ripple frequencies available, the first frequency can be used for " all lights on," the second for " side-street lamps off " and the third for " main-street lights off." If in the event of emergency it is necessary to switch both side and main street lights off, frequencies 2 and 3 may be sent consecutively.

The installation of relays provides no features of interest. The relays are normally contained in small cast-iron boxes of dimensions comparable with those of a time-switch.

Relays have 4 terminals, 2 for supply and 2 for load, the separation of the operating ripple from the load being effected internally in the relay in the manner already described.

(ii) Off-Peak Control.

Of all the applications of the ripple control principle, its application to the stimulation of the economical development of off-peak loads is one of the most attractive.

It is becoming generally accepted that a very large market exists for thermostatically controlled electric heating and large water-heating installations at tariffs not in excess of ½d. per unit.

It is furthermore generally recognized that an unrestricted rate of ½d. per unit can seldom be justified on economic grounds, if the load infringes on the annual maximum peak to an extent greater than about 15 % of its connected demand.

Undertakings who buy electricity at grid rates are compelled to recognize this more realistically since each kilowatt of maximum demand has a fixed price, and the cost of maximum demand does not tend to be submerged in the general costs of supply.

Undertakings operating selected stations are in the same position, although they do not buy their maximum demand kilowatt by kilowatt but in large units represented by the capital cost of generating equipment. They, however, have an equal incentive to limit maximum demand on existing loads where such limitation can be imposed and also to develop off-peak loads for improvement of load factor.

If, for example, a water-heating installation is controlled by time-switch, the degree of inconvenience inflicted on the consumer by a daily interruption of supply of 2 or 3 hours is generally penal, and as a result time-switches are not extensively used for such purposes.

Since it is only necessary to interrupt supply when a real peak is in progress, the use of ripple control enables the whole financial benefit of an off-peak load to be obtained by the supply company with only the minimum of interruption of the consumer's supply, since the interruptions can be effected from the central station only if the maximum demand threatens to be an annual peak.

It is generally held that the advent of ripple control must lead to a great stimulus to the profitable development of heating loads other than electric radiators.

(iii) Special Tariff Systems.

In order to meet the requirements of particular types of consumers or classes of load, supply authorities have been led to adopt a wide variety of special tariffs designed to suit the particular needs, for example, of large power consumers, off-peak pumping, etc. The application of such tariffs generally involves either an interruption of supply at peak times, double-tariff metering, or some form of maximum-demand metering.

If the rate changes or supply restrictions operate at fixed times on every day, a clock switch can be used for performing the operation. On the other hand, it is always possible to give a more satisfactory tariff with less onerous restrictions to the customer if the supply authority need only impose its maximum-demand penalties at such times that the consumers' maximum demand is coincident with the system demand. This applies where maximum-demand or double-tariff metering is employed.

The employment of ripple control enables a more liberal attitude to be adopted by the supply authority, by reducing the number of hours per annum during which maximum-demand penalties may be incurred.

While it is outside the scope of this paper to discuss the various methods which can be or have been employed to this end, ripple control offers the most stimulating and intriguing possibilities in the application of special tariffs.

(iv) Display Lighting.

Most undertakings nowadays offer special rates for the lighting of shop windows, hoardings, and general publicity purposes. Such special rates generally have a time clause in them, and if an undertaking possesses a multi-frequency ripple control system it may be advantageous to allocate a pair of frequencies for the control of this load.

It is highly advantageous to be able to interrupt display lighting circuits centrally in the event of war.

(v) Control of Switchgear.

Although ripple control is not primarily designed for the operation of single relays for such purposes as the remote control of circuit-breakers, it is an attractive possibility of the system that an undertaking already using ripple control for other purposes can set aside a few frequencies for the control of switches in isolated substations. This particularly applies in rural areas where such substations may be very inaccessible.

Although such applications do not financially justify centralized ripple control, they form an attractive makeweight in the consideration of the system.

(vi) Air-Raid Precautions.

The question of air-raid precautions is now so much in the public eye that the unique merits of ripple control in this field are even tending to overshadow the less sensational but perhaps more valuable merits of the method discussed earlier in this paper.

It is now widely understood that local authorities in the event of war must perform certain operations. In the event of threatened hostilities, all street lighting must be extinguished or severely restricted. This regulation is a very severe one, but was presumably necessitated by the difficulty in centralizing the control of gas lighting in those areas where it still exists.

Although to comply with this regulation local authorities will only have to perform the emergency extinction once in the course of a war, many authorities are considerably perturbed at the possibility that the warning that a state of tension has arisen might give them insufficient time to switch out the street lighting if locally controlled by time-switches.

In areas where public lighting is controlled by some thousands of time switches, this operation might easily take 8–10 hours. During this period an air attack might be delivered without warning, and it is a disastrous possibility that enemy aircraft might reach these shores to find large industrial towns brilliantly illuminated, while the staff of the electricity undertaking frantically endeavours to draw the fuses on some thousands of lamp-posts.

It appears obvious that no Government can guarantee the length of warning period that can be given since it would be unable to define that exact state of tension which might prelude an air attack, and would obviously hesitate until the last possible moment, for fear of unnecessary public alarm, to issue the regulations that streets must be darkened.

Thus the installation of some form of centralized control appears to be a necessity.

It is sometimes thought that in an emergency it would be practicable to cut off the supply altogether. This is understood not to be permissible, owing to the necessity of avoiding undue public alarm and maintaining essential services even during the course of an air-raid.

Furthermore, it has been remarked that if a large generating station were suddenly relieved of all its load, the resulting plume of steam which would arise as the boilers blow off would provide an excellent indication to attacking aircraft of the location of their most cherished target.

Control of restricted lighting.—It appears probable that in many areas very restricted lighting will be permitted during war time, provided that it can be instantaneously extinguished.

Many take the view that such restricted lighting will be highly desirable, for some pessimists think that a state of tension necessitating active precautions might continue for a period of years without actual aerial attack. A state of total darkness might lead to considerable increase in crime.

The view has also been expressed that in industrial areas there is a risk of looting and shop-breaking taking place unless some restricted lighting can be restored after an air-raid.

Operation of warning sirens.—A centralized ripple control system can be used for the operation of warning sirens over a large area. This is already practised in Paris.

The ripple frequency that is used to start warning sirens can also be employed to call air-raid wardens in their homes by the aid of a portable relay comprising a bell, which can be plugged into any socket on the network and which could, if necessary, be carried about by a warden, in a state of emergency, so that wherever he might be located he could plug in the relay and be available to answer a warning.

It is suggested that to provide complete public-lighting control and air-raid precaution services, four ripple frequencies should be set aside, viz:—

Street lights " On."
Street lights " Off."
Warning sirens.
Air-raid warden mobilization.

After the first alarm at the commencement of a war it would presumably be possible to draw the fuses on all street-lighting circuits other than those required for the permitted restricted lighting, and thereafter during the course of a war the on and off frequencies would control the restricted lighting only.

It seems to be essential that the control of these services must be effected from the generating station and not from substations, unless a complete system of pilots existed by which local transmitters in substations could be operated. The cost of such a pilot system in most areas is quite unthinkable, and it is concluded that only the centralized method can provide the service required.

(7) CONCLUSION AND ACKNOWLEDGMENTS

In outlining the technique of ripple control and discussing its application to the control of various services, the author has entered some fields of discussion not appropriate to a paper of this kind.

He hopes, however, thereby to stimulate fresh information and criticism, and to cause the attention of the industry to be attracted to the study of the far-reaching possibilities of centralized control systems.

Many uses for ripple control which are not mentioned in this paper may be envisaged, and individual supply authorities are more competent than the author to devise applications most suited to their particular needs and circumstances.

Regarding air-raid precautions, it is to be hoped that this particular application of ripple control is of only transient importance, and it would be deplorable if this particular use were to be thought to constitute the prime merit of the system.

The author wishes to express his acknowledgments to the following firms, whose published matter he has consulted: Actadis, Ltd.; Compagnie pour la Fabrication des Compteurs, etc.; Siemens-Schuckert A.G.; The American General Electric Co.; The Automatic Electric Co.; Standard Telephones and Cables, Ltd.

He has also referred to the English and foreign technical Press, and to papers by the following:—

B. H. LEESON: International High-Tension Conference, 1935.

M. CHIROL: International High-Tension Conference, 1929.

W. DUDDELL, H. W. HANCOCK, and A. H. DYKES: *Journal I.E.E.*, 1913, vol. 50, p. 240.

DISCUSSION BEFORE THE TRANSMISSION SECTION, 11TH MAY, 1938

Captain H. Pryce-Jones: We in Liverpool have had some experience of control by impressed frequency, as we have in service some 4 000 relays which are operated by a sub-centralized system based on the earth-return method. As the troubles to which the author refers have been almost entirely absent, I cannot agree with some of his remarks on these systems.

I should like to ask whether he has any knowledge of a third class of superimposed control systems which embraces both the classes mentioned in Section (2)(*b*) and combines their advantages without incurring their disadvantages. The method adopted in this third system is to centralize the control on the high-voltage distribution system and impress upon this system a very low-power signal. This signal is amplified at the substation by a valve system, and the operating impulse is communicated to the low-voltage local distribution system.

In Section (3) the author lays great stress on the disabilities of the earth-return system, but later he admits that the system has certain merits and that the power required is nothing like what he had expected it would be. Perhaps he would be good enough to explain that apparent contradiction. He admits that the operation of the earth-return method may be rendered satisfactory, and I think one must accept this admission rather than his preceding statements, in view of the fact that in Great Britain there are some 10 000 relays in operation on this system.

I am very interested in the star-neutral method, which has been applied, I think, on an installation at Erith. The point that occurs to me in connection with it is this: while the Commissioners' Regulations approve the insertion between neutral and earth of an impedance, I am not at all clear that their approval has extended to the inclusion of an impedance in the star neutral. Have the Regulations been infringed by the application of this principle? This point also applies, of course, to the d.c. bias principle illustrated in Fig. 4.

In Section (4) the author says that "the propagation of the ripple can be considered distinctly from the propagation of the load, and, from the point of view of calculation, the load can be neglected . . ."; and farther on he says "Since the ripple utilizes the same circuit as the load, it must . . . be absorbed by every piece of current-consuming apparatus on the system." I do not see how those two statements can be reconciled. If the ripple is absorbed by every piece of current-consuming apparatus, however small it may be, on a very large distribution system the energy absorbed must be appreciable. The point is important, in view of the fact that the author has to put in a 30-kVA generator.

Also in Section (4) the author states "the amount of ripple absorbed by the system decreases as the frequency rises." This is all very well if the circuit is an inductive one, but it requires a certain amount of qualification with respect to the capacitance loads which are connected nowadays to improve the power factor of our systems. I should like to know whether the author has experienced any serious difficulty in catering for networks where a large amount of power-factor-correction capacitance is used.

Mr. H. Nimmo: One or other of the systems mentioned in the paper has been in use in this country and in America, Germany, Belgium, and France, for some years. The author would have us adopt the Actadis system which is now standard practice in the French capital, where I have seen the system in operation on two separate occasions. There are 28 Actadis emission plants in Paris, operating on the six principal undertakings and controlling a very large number of street lights and triple-tariff meters. These plants are used for cutting off certain loads at peak periods, and for air-raid warnings and other

devices. They operate, I believe, about 3 000 times per month, and there has not been a single instance of failure. The first plant was installed in 1928 and the whole scheme was completed in 1936. It is now the largest centralized street-lighting control system in the world.

The author seems to prefer the method of using the system shown in Fig. 7, i.e. injecting high-frequency ripple into the medium-voltage feeders. This method has been adopted at Maidstone where it is operating perfectly satisfactorily and, except for one defective relay, no failures have been experienced on any part of the equipment.

I had the privilege of inspecting the Actadis installation at Versailles, which operates on the principle shown in Fig. 8, namely the high-frequency ripple is injected into the incoming high-voltage supply feeders. In spite of the triple-tariff meters which have been installed at Versailles to encourage off-peak loading the supply company had only succeeded in raising the load factor to 30 %.

Mr. F. C. Orchard: I shall confine my remarks principally to the Summary, in which the author says that " recent developments in this field have placed in the hands of the supply industry a powerful weapon with which to attack the economical development of heating loads. . . ." Surely the author has a wrong conception of what an electricity supply industry represents. If the electricity service is to be a service, any question of restricting the use of energy is surely not in the best interests of the industry. I presume that the author's main fear is peak load, but if we are to try to avoid accepting any load which is likely to cause a peak we are going to be in a position of great difficulty. I do not see why we should cut out water-heating over the peak period. In the case of my own borough, we attain our peak generally in the winter months about 5 p.m., and the peak is flat until after 11 p.m. If I cut out water-heating entirely over the peak, I am therefore cutting out water-heating for 6 hours out of the 24, thus making it hopeless to try to develop a water-heating load. I might just as well say that I should cut out the use of cookers, because they come on during the peak-load period. The two suggestions are equally absurd.

I maintain that the only use for a ripple control system is for street lighting; in fact, I think that the other uses have been attached to justify the very high initial cost of the gear. In my earlier days I was responsible for installing a large number of fully automatic rotary-convertor substations, and I have painful recollections of locating faults on inaccessible relays. I imagine that in a short time—perhaps 3–4 years—those who are responsible for maintaining the gear described in the paper will be faced with many similar difficulties.

When I had to take over the street lighting of Hornsey, and started the change-over from gas to electricity, I investigated the ripple control system with the author, but owing to its high cost it had to be put on one side and another system investigated. I finally decided to recommend to my Council the d.c. bias system, briefly referred to on page 826. According to the author this has certain limitations, but I have been operating this system for some time and I have not found any. It may be of interest to recall one experiment which I made. There were two substations approximately $\frac{3}{4}$ mile apart, one substation only having d.c. bias substation equipment installed. On trigging off, I found that the relays on the posts operated up to the point where the second substation fed into the network of the first, i.e. with all three phases of both transformer systems coupled through fuses to one linking point. After the one transformer substation had been switched out the whole of the street lamps in the area of the combined substations could quite easily be managed by a 6-volt 120-ampere-hour battery. A second biasing panel was later installed in the second substation, and it was then quite possible to trig off both equipments, not necessarily together, and supply the area.

At the top of page 827 the author says " it is very difficult to see how the bias method could be applied to any network fed from more than one substation. . . ." I can only say that my experience shows that there is no difficulty in doing so. As regards false operation of relays due to transients, I have unfortunately had one fault in my area, but I have had no trouble due to relays operating under a false bias, and I cannot visualize any bias being applied of such a magnitude as to cause the relays to operate.

I should be glad to know whether the Maidstone Corporation investigated other systems before deciding upon ripple control of public lighting, what conclusion they came to with regard to initial costs, and whether they decided to ignore the question of future maintenance costs.

Mr. J. F. Mackenzie: Dealing first of all with the earth return system, referred to on page 825, it has been argued that advantages accrue on this system because earth faults are automatically indicated through the disabling of the system. It is a fact that supply engineers have requested the present-day exponents of this system to provide high-frequency emitters for detecting faults on the neutral. (Apparently these supply engineers are more conscientious with regard to observance of the Commissioners' Regulations than is indicated in the paper.) It has proved impossible to do that, however, because the impedance on the networks is such that it is not possible to localize a fault by putting an earth or a short-circuit on any part of the network.

With regard to the selection of the ripple frequencies (page 828), there is an important point to which I should like to refer. No reference is made to the influence exerted by the mechanics of reeds; it would seem that the lower-frequency reeds are desirable on account of their greater sensitivity. Obviously the higher the frequency of the reed the stiffer and the less sensitive it becomes. In view of the relative freedom from harmonics at higher frequencies, however, the application of higher frequencies would appear to be preferable; but, against this, the relative insensitiveness of high-frequency reeds may prohibit their application. This point is, of course, considered apart from other aspects such as attenuation.

In Section (5) of the paper two methods of applying reeds to relays are mentioned. I think that in honour of Oliver, Pell, and other pioneers, some mention might have been made of the alternative and very ingenious method of interrupting a high-frequency impulse in order to obtain a low-frequency beat on the reed. The " Olipell " system emitted a frequency which was relatively high

because it was used only on direct current, and chopped that up again into about 10 impulses per second, to operate a low-frequency reed which was sensitive and functioned down to about 2 volts. Another advantage of that system is that it gave relative freedom from harmonics. The selection of frequencies indicated in the paper is evidently made to avoid the harmonics of 50 cycles per sec., which are quite considerable. Another feature of the Olipell system is its greater simplicity of selecting the facilities compared with pure frequency-selection. When the frequency is altered to get a different relay to respond, it becomes necessary to alter the value of the tuning condenser in order to tune in. With the system advocated by the author an expensive condenser is required for every frequency it is necessary to select, but if we chop the one frequency up it is only a matter of using a single condenser and a contactor, a much cheaper arrangement.

It would be interesting to learn whether all the frequencies mentioned by the authors have been applied in practice, or whether they are merely theoretical values.

The application of the "parallel" method of ripple emission (Fig. 6) may be thought by some to be impossible, or at any rate restricted with respect to the high-frequency energy superimposed. Such restriction would appear advisable because the conditions necessarily involve the introduction of the ripple into the national grid and consequent encroachment into the networks of adjacent undertakings. It may be argued that in view of the low impedance across the grid busbars the potential is so low as not to constitute a source of interference, but of course the network conditions control this point. Where one ring main is shared by several undertakings, it would be a definite encroachment. Again, it is quite possible that a system may be evolved which is more sensitive, and such a system would put a legal liability on the undertaking causing interference and perhaps offer serious legal implications. This method was illustrated in the *Electrical Review** and stated to be suitable for networks up to 10 000 kVA. Is its use contemplated on any of the other installations in course of erection to which the author refers?

On page 828, dealing with the series-emission method, the statement appears that "The ripple is propagated only towards the consuming end of the system and cannot interfere with an adjacent undertaking fed from a common bulk-supply system." That statement is difficult to reconcile with the previous one that "only a small voltage appears across the source of supply." In view of the previously-mentioned implications of interfering frequencies, some amplification of the point would be of interest.

From page 830 it would appear that the factor controlling the size of the high-voltage generating plant is the cross-section and current-carrying capacity of the feeder, and I should be glad of confirmation of this. Moreover, the qualification that the equipment would be adequate for the ultimate demand *unless the scheme of distribution was radically changed* is an important one which needs serious consideration. Feeder sections frequently become inadequate to cater for ever-increasing loads, and it is quite common to overcome this difficulty by laying subsidiary feeders, perhaps in a ring-main formation with higher voltage, in order to boost and relieve loads at a distant point. This convenient method of catering for an ever-present difficulty would appear to be prohibited by the adoption of this type of ripple control.

The statement appears on page 830 that the magnetizing current has to be compensated by capacitance; I should be interested to learn why that is necessary, because it seems to involve rather heavy expense.

Apparently a good deal of expense is also incurred in ensuring that the ripple voltage is constant. The relay, it is presumed, has certain voltage limitations, and consequently it becomes necessary to test for the load and adjust the output accordingly. If the relay could be made to have a greater latitude the economics of the system would probably be considerably improved. A further point is that in highly inductive networks considerable attenuation is to be expected. Certain d.c. networks, for instance, utilize single cables in conduits, with consequent high inductance and considerable voltage-gradient on a high-frequency emission. I should be interested to learn whether any such difficulty has been experienced. Has any difficulty been encountered regarding high inductance on the d.c. networks in Paris, or has an alternative system of more recent design been installed there to overcome the voltage-gradient trouble?

A brief reference is made in the paper to other types of relays, and I should be glad of further details of these. No mention is made of the sensitivity of the relay employed on the Maidstone system.

Mr. A. H. Dykes: This paper carries my mind back to a spring evening 26 years ago when, in a cellar about 6 miles from the Egham generating station, the late Mr. Duddell, then President of The Institution, my late partner Mr. Handcock, and I, were anxiously watching a small wooden box on the top of which was mounted a lamp. The reason was that 2 years before, in 1910, Mr. Handcock and I had patented a system for affording control all over an electric system of mains by means of ripples interjected into the system from the generating station. In the Egham station we had a small alternator, belt-driven from a motor, and we connected our relays to the mains at a point 6 miles away. It did not seem to us that there should be any difficulty in picking out the ripple on our relay, because we had tried it close at hand and it had worked successfully. We arranged with the staff, therefore, to switch on the ripple at 6 p.m., wait 20 sec., switch it off again, and then repeat the operation. Six o'clock arrived, and nothing happened; it was not until 6.10 p.m. that, to our intense delight, the lamp began to flicker. On getting back to the station we found that the reason for the delay was that the staff had managed to throw the belt off the small alternator.

In September, 1912, we read a joint paper* giving the whole theory of the ripple system, and dealing particularly with the question of resonance. A second patent was taken out in 1912 in the names of Mr. Handcock, myself, and Mr. Duddell, dealing with most of the applications, and other patents were taken out later in which Mr. Oliver and one of his associates, Mr. Andover, joined. In 1912 we worked out the requirements for applying the system to Tunbridge Wells, and in 1913 to Marylebone,

* *Electrical Review*, 1936, vol. 118, p. 778.

* *Journal I.E.E.*, 1912, vol. 50, p. 240.

but then the War began and our work was shut down; it was not until 1917 that the first full-size trial was made, at Leatherhead.

It is stated in the paper that it was not until 10 years ago that any appreciable work was done on this subject, but in fact at Leatherhead in 1917 the network stretched from the Guildford boundary to Epsom on the one side, and from Twickenham to Dorking on the other, a matter of some 54 square miles, and, although the load was not very great, it was at any rate of the order of 1 300 kW. One plant was installed, with a throw-over switch to work either on the 3-wire d.c. network which fed Leatherhead itself or on the high-voltage 3-phase network which fed the outlying districts. The installation worked the public lighting throughout the district and was used for switching relays in one or two substations, and also for one or two special lamps which had to be left burning until a certain time in the night.

The system was rather more complete than is the one described by the author, in that in addition to injecting into the mains a high-frequency ripple to which the relays were tuned we varied the pulsations, and, depending on the pulsations, so any particular relay worked. Before any relay could work, therefore, a current of a particular high frequency had to pass, and it had to be fairly sharply regulated and to be applied at the right number of impulses. These impulses were given by making and breaking the exciting circuit of a little alternator which injected the ripple. In the Leatherhead plant the pulsations were controlled by means of a pendulum, and the whole system was fully automatic.

In 1920 the system was adopted for public street-lighting over the whole area of Winchester, and at Tilbury and Crayford, and in 1923 it was put in at Douglas, Isle of Man. This last was a rather interesting application, because in our original patent we emphasized the advantage of being able to charge different rates for energy at different periods of the day by meters, the idea then being to switch the meter off by breaking its shunt circuit 1 minute in 5, 1 minute in 6, and so on; so that it was possible to meter $\frac{1}{5}$ or $\frac{1}{6}$ or any desired multiple of the actual units being taken, letting the consumer have more current during hours when current was cheap, and on the peak load metering it all. At Douglas at that time there was no power load, and the difficulty was to persuade people to use energy at all during the day. Some of the shops there, however, were very long and had very little light at the back, and so we charged one price for energy from the beginning of the peak load until 11 p.m., and from 11 p.m. until the beginning of the peak load next day we charged a much lower price; the meters were changed over by means of the ripple system. So far as I know the system is still working satisfactorily to-day.

I think that in fairness to Messrs. Oliver and Pell, and the work of English engineers, the above facts should be put on record.

Mr. C. Oliver: I should like to give a few details of the way in which we applied this system 20 years ago. The system employed for the installation at Leatherhead was almost identical with that described in the paper. The generating station was in the centre of the town, and it supplied direct current for an area about $1\frac{1}{2}$ miles in diameter; the outlying districts 6–7 miles away were served by a 3-phase high-voltage system. The only way in which our system differed from the author's was that we had pinned our faith to a timed oscillation in combination with the superimposed frequency, and this entailed a somewhat more complicated method of controlling the plant at the sending station. But it gave us what the author's system does not, a much greater number of uses for the system, because with the combination of these two frequencies we could obtain up to 36 different switching speeds. Probably we were before our time in taking the trouble to do this. The author seems to think that only 8–9 speeds are required. My experience, is, however, that the 12 or 14 speeds which we normally provided in those days were employed almost at once, and I feel quite sure that finality will be secured only by the system capable of switching a considerable variety of loads, quite impossible with the limited capacity of the author's system.

The voltage of the superimposed ripple at Leatherhead, and indeed at most of the other places where the Handcock, Dykes, and Duddell system was put to use, was round about $2\frac{1}{2}$ % of the station voltage. Will the author tell us the ripple voltage he uses?

The greatest difficulty we encountered 15–20 years ago was in the application of the ripple system on d.c. networks. The author does not say how he has tackled this d.c. problem at Maidstone and how he injects his ripple. In d.c. stations in particular I have found great variation in the conditions. In many cases the mains would not pass these ripples without excessive loss in voltage. In one London borough we could not get the signals through even at $\frac{1}{4}$ mile from the generating station, because the cables were laid in iron pipes.

My experience shows that, speaking generally, ripple switching is in a number of cases a sound engineering proposition and can be carried out successfully, but intricacies in many supply systems make the ripple system of control difficult, if not impossible, to apply. The value of ripple switching from a practical standpoint depends upon what use can be made of such an expensive adjunct to a supply system.

The type of load whereby the valleys of the load diagram can be levelled or even reduced exists at present in a very minor degree, if at all. Until such a load can be found I cannot envisage ripple switching coming into its own. In consequence I am rather inclined to suggest that one or other of the cheaper forms of local switching will in most cases suffice for present-day needs.

There is another point I should like to mention, namely that if one has a ripple plant designed for a station and its network one cannot change one's plans later on and feed in another supply independently unless one brings back the new supply to the main station and ripples it first. All sorts of impossible conditions are apt to crop up if one wishes to do something maybe a little unorthodox.

Mr. E. M. S. McWhirter: It seems to me that fundamentally the author is at fault in plumping for centralized control over a high-voltage network. Many undertakings employ pilot wires to couple up their substations, and large numbers of undertakings are laying pilot wires whenever they put in high-voltage feeders or substations. There is no disadvantage in using pilot wires as a means to link substations to the central control point, but there

are considerable advantages in so doing, because (*a*) pilot wires are much more easily maintained than any equipment connected to the high-voltage system, (*b*) local operation of the equipment at each substation can be performed. Thus pilot wires have the advantage of both localized and centralized control, and are therefore particularly suited to the requirements of air-raid sirens.

If the application be considered of a ripple system to a large city network involving an e.h.t. supply through, for example, ten 33-kV substations, then it would seem necessary to install ten ripple-emitters, one in each substation. Since these substations may either be interconnected or not, it would seem to be essential to arrange for the ripple transmitters to be synchronized, and presumably this would have to be done by pilot wires. The only alternative is by parallel transmission of the ripple wave, which is ruled out on the score of cost.

I do not know how long it would take to put ripple transmission on hundreds of feeders by the series method. Perhaps the author would be good enough to indicate the time taken for, say, 300 feeders to be energized.

My next point is that the author must energize his feeders simultaneously if they are paralleled on either the high-voltage or the low-voltage side, and again I do not see how this is possible on a very big network. To install an additional network diagram for the sake of paralleling the feeders, so as to provide the emission all over the system from a central point, does not seem to be quite the right solution or one that is readily workable on a complicated network.

I should like to suggest the use of a localized system such as the d.c. bias system, which has the advantages of lower cost and easier maintenance. Moreover, the equipment is wholly at earth potential, very robust, and simple to install. I have actually taken d.c. bias equipment in a motor-car, stopped at my destination, and had the equipment working inside half an hour. I think that the author is mistaken when he refers to the equipment as being complicated.

Again, with ripple emission why is it necessary to control the load and speed so carefully? If one wants to supply various different amounts of energy at constant voltage to the network, a d.c. battery is the ideal solution, as it will give good regulation over very large fluctuations.

In paragraph (*c*) on page 827 the author says that no economical method of providing a number of facilities for the d.c. bias system has been devised. I should like to mention a recent article* in which a very simple receiving unit is described which will give a total of 13 different selections, as against the author's 12.

The question of transients on d.c. systems seems to worry the author a good deal, but I can assure him that just as in his ripple relay he allows a certain time for ripple emission, so that a sudden kick, as from a lightning surge, has no effect, so in the d.c. bias system a certain period can be allotted. This can be done more simply than in his system by using the inductance winding of a transformer, giving a delay of about $\frac{1}{3}$ sec. Any transient which persists longer will almost certainly be an a.c. transient, and, as such, it will not affect the relay. Finally, has the author had any experience of applying a ripple system to a d.c. network, and as a result found that existing commutator ripples make a ripple signalling system in some cases unworkable?

* *Electrical Times*, 1938, vol. 93, p. 305.

Mr. E. Hallowell: It would appear that the fundamental difficulty associated with ripple control schemes is the loss of control energy through the ohmic load on the supply system, and, since this loss varies with the square of the applied voltage, considerable power must be injected to operate simple inexpensive relays at remote points of the system. Furthermore, serious attenuation may occur due to conditions of resonance on long spur lines terminating in underground cable, and power-factor-correction condensers may cause similar effects. I should like some information as to the minimum power necessary to operate the street lamp relays used in the centralized control system described in the paper.

My own experience in applying a control system to a large multiple-voltage supply system leads me to favour the injection of a comparatively small amount of ripple control energy at the central station, and to repeat and amplify this at low-voltage substations. The repeaters employed are purely static, incorporating a new form of frequency-multiplier utilizing saturated chokes and condensers. In addition to increasing the reliability of the control system, this arrangement has the virtue of permitting subsidiary control of off-peak load according to the demand at individual substations.

The method of injecting the whole of the ripple frequency at the central station, as described in the paper, calls for comparatively low injection frequencies which to my mind approach dangerously near to the normal harmonic frequencies. The 7th and 9th harmonics are often particularly pronounced during light-load periods, e.g. during week-ends, and have been known to reach an amplitude sufficient to burn out power-factor-correction condensers, under conditions of resonance. According to the paper, 370 cycles per sec. is used for the "on" sequence of street lights, and it would appear that there is a possibility of interference at this frequency. My own experience is that frequencies of 900–1 400 cycles per sec. are the most free from interference, and when used in conjunction with repeaters at low-voltage substations are comparatively free from attenuation troubles. The use of such frequencies also permits the employment of the simple parallel method of emission, which is not suitable for the lower frequencies. I do not share the author's opinion in regard to the inefficiency of the parallel method of emission. It must be remembered that most supply systems are connected to a grid system of infinite capacity, and therefore the ripple current flowing back through the main transformers is almost entirely wattless and limited by the transformer reactance; in fact, the transformer serves as a useful loading coil in balancing the cable capacitance, when the injected frequency is of the order of 1 000 cycles per sec.

Mr. W. F. Russell: I am disappointed that the author does not pay more attention to the d.c. bias method. I feel that there is a considerable future for this system owing to its cheapness, reliability, and simplicity; and, although he may term it a localized system, I would say that it is also being successfully applied centrally on my own undertaking. The paper proves that more atten-

tion should be paid to the provision of pilot cables between substations. The d.c. bias equipment has an advantage, because the saving in capital cost which it makes possible will pay for the rental of many miles of telephone pilot wires.

I have had to supply a scheme for the control of street-lighting and other services, and have therefore had to consider the cost of maintenance and of staff. To a comparatively small undertaking, the expense of engaging an expert to be responsible for a system such as the author describes would be very considerable. The ripple emission system contains a considerable amount of plant which has to be manually controlled, it is no doubt expensive, and the earth-return system is liable to be upset by accidental earths. I therefore decided to install the d.c. bias method, and it is giving excellent service. The cost of installing the signalling appliances and 40 alarm units for summoning air-raid wardens, the control equipment for the large compressed-air-operated sirens, the control equipment for all-night lighting, and the mass control panel, was less than £1 000.

I do not agree with what the author says on page 827, where he states that " No economical method has yet been devised of providing a number of different selective operations on the bias system, which prima facie can only provide two main discriminations by polarity reversal." The arrangement which we employ is non-sequential and does not get out of step, as he suggests. About 0·5 sec. is required for the relay to operate, and I do not imagine we shall have any trouble in that connection. The author also states that his objection to the scheme is that it is localized. To my mind this is an advantage, because two or three different undertakings would not wish to receive the signals from the main supply, as they would probably have their own, and would have other services to perform. In my opinion the d.c. bias method is extremely simple, cheap, and easily installed.

Mr. E. A. Logan: Some mention has been made by previous speakers of the application of ripple systems of control to the introduction of multi-rate tariffs for electricity supply. I hope that this suggestion will not be taken seriously by supply engineers, as we have some 600 undertakings in this country, each already with a number of different tariffs.

Some years ago I considered the possibility of using the pilot system for the control of consumers' load, but found a difficulty in that while the pilot is already taken into street-lighting columns or substations it would be costly to take a service from the pilot into each consumer's premises for the purpose of operating load-control relays.

It is considered that in paragraph (*b*), page 827, the author probably exaggerates the effect of transients as a limiting factor in the case of the d.c. bias system.

I should like to ask whether the ripple added to the curve of Fig. 5 has any effect on the r.m.s. value of the system voltage. With regard to Fig. 10, I presume that the frequency-excited reed will have the ordinary resonance curve, and mechanical damping will tend to flatten the curve and extend the frequency over which the reed can operate. Again, if the voltage on the relay is excessive, this will also tend to extend the range of operating frequency. It would be interesting if the author could state what percentage excess voltage would make the on-and-off frequencies overlap.

Mr. Oliver raised an interesting point in connection with such systems of control as are described in the paper, namely that the supply engineer is primarily concerned with electricity distribution to consumers. Any factor which tends to limit the engineer's freedom to interconnect his system in an emergency is to be deprecated. Perhaps the author would outline some of the limitations which ripple control imposes on the operation of a supply.

Mr. E. A. H. Bowsher: In Section (4), reference is made to a frequency of 500 cycles per sec. at 1 000 volts being superimposed on high-voltage feeders. Have any tests been made to ascertain the amount of inductive interference that such a voltage and frequency can cause on neighbouring lines such as telephone circuits? It would also be interesting to know to what extent domestic broadcast apparatus is affected, and whether the ripple system has been applied to networks supplying power to sound-recording gear or sound-film apparatus, where I imagine the results of any such inteference would be considered to be much more serious.

In discussing the interaction of two substations, the paper says that where the network is fed from more than one substation it is advantageous if the bias transmitted from Substation A is diminished to zero at the terminals of Substation B solely through its dissipation in the phase-to-neutral load. With the d.c. bias system, however, it is found that if one connects a 240-volt supply to one end of a feeder and a drop of 6 % is obtained at the far end, then when the bias of, say, 6 volts is applied, the bias obtainable at the far end is 6 volts less about 6 %. Thus the bias is never diminished to zero solely through its dissipation in the phase-to-neutral load, and no advantage would be obtained if it were so diminished.

Dr. W. L. Stern: With regard to air-raid precautions, I should like to draw attention to a point which will show that nearly all the systems described in the paper are somewhat dangerous; and, as the author particularly recommends the system which he has used at Maidstone, I should like to confine my remarks to that.

If an electricity undertaking has installed a transmitter of the kind employed at Maidstone, it would be easy for an unauthorized person to give a ripple transmission in parallel to the network. The author gives in Fig. 6 a wiring diagram of the transmitter which in my opinion could easily be used for interference purposes from any point on the network. An unauthorized person has only to transmit a frequency of 370 cycles per sec. for a few seconds and the street lighting will go on in the area covered by the unauthorized transmitter. It is not even necessary to know the exact frequency; it is only necessary to raise the frequency slowly from 300 to 400 cycles per sec., and, if the first test proves unsuccessful, it will be easy to find out the exact street-lighting on-frequency. A similar remark applies to the frequency used for the air-raid alarm; it would be dangerous if an unauthorized person could give a signal which meant, for example, the end of an air raid. It seems to be difficult to apply special safeguards in order to avoid interference in the case of air raids. Under normal conditions, however, the super-

imposing of frequencies for remote control will be successful.

Mr. J. A. Prowse: I should like to emphasize the commercial aspect of centralized control.

Before installing a control system it is necessary to make out a good case for the displacement of existing time switches, and also to take into consideration possible future developments. Gas competition in many areas, of a kind which often brings no profit to the gas undertaking, means that there is only a very small margin of profit to the supply undertaking which has secured or retained the business, and unless the proposed system can show or promise a financial advantage over time switches there is difficulty in securing its installation. If public lighting is to be made the starting-point for the introduction of the system, perhaps the author will be good enough to give his views on whether there will still remain a case for the installation of cheap independent transmitters located in individual substations, even if they are eventually to be displaced by a more comprehensive transmitting system situated centrally.

Mr. E. M. Lee: I do not like the use of the terms "high frequency" and "audio frequency" in the sense in which they are employed in the paper. I think that it is much better to use the word "ripple."

A good deal of use is made of condensers between neutral and earth for suppressing radio interference. In some districts, particularly where there is a number of detached houses, the cheapest method for the listener to use is condensers of 1 or 2 μF connected to the incoming mains. Objection has been raised by certain undertakings to these condensers, because of the fear that they would upset street-lighting systems. It has been found, however, that even if all consumers had such condensers on their meter boards, owing to the low impedance of the mains and the comparatively low frequency being used the signals would still get through. I should like the author to state what effect such a multiplicity of condensers on a system is likely to have in connection with the various schemes described in the paper.

Mr. S. J. Patmore: Supply undertakings should pay more attention to the allocation of the various items of cost relating to street lighting, such as the cost of providing the supply, the cost of providing labour, the division of the labour costs, etc., to enable them to judge more equitably the advantages of any schemes of this nature which may be put before them.

I presume that the relay shown in Fig. 10 would be fitted with three reeds instead of two when used for half-night and all-night lighting. If such is the case, would it be advantageous from the point of view of standardization for all the relays on a particular system of street lighting to be of the 3-reed type, or should this type be adopted only for those points where extra control is required?

I should like to ask the author to state the effect of dampness on the operation of these relays. At the Empire Exhibition, Glasgow, the relays operating the contactor gear for the dimmer circuits on the coloured-lighting fountain displays have been placed in a basement where the pumps and their control equipment are housed, and I understand that although no water penetrates into this basement, there is some dampness in the atmosphere which is causing the relays to give a certain amount of trouble. I presume that similar difficulties may be met with in connection with street-lighting relays, particularly during periods of inclement weather.

I agree with Mr. Oliver that it is advisable to have as many ripple frequencies as possible, which may be utilized for different purposes as an undertaking which has installed a system of control of this nature will, as time goes on, find more and more use for it.

While Mr. Logan and other engineers do not like the idea of providing special tariffs for ripple-controlled circuits, it seems to me that they might get some advertising value from it by providing their consumers with a free alarm service, whereby a consumer could be called at any predetermined time between 6 a.m. and 10 a.m.

Mr. H. Purslove Barker (*in reply*): I propose to reply to each of the speakers individually, except where other speakers' remarks constitute replies with which I am in agreement.

Captain Pryce-Jones points out that in Liverpool the earth-return system operates satisfactorily, but, since it is known that this technique has not always given satisfactory results in this country, the Liverpool experience does not in itself refute my contention that the success of this technique is capricious, and too dependent on variations of neutral insulation and distributed capacitance. As regards the operation of local slave transmitters in substations by a master transmitter in the generating station, this is quite a practicable method, but it suffers by comparison both in cost and convenience with centralized ripple systems. Regarding the application of ripple control on networks where a large amount of power-factor-correction capacitance is used, individual relays have been known to fail when located virtually at the terminals of a power-factor-correction condenser bank. Such a trouble is purely local, and can be easily remedied by appropriate compensation in the relay. This factor, however, need not be taken into account in planning a ripple transmission installation.

Mr. Nimmo observes that the employment of ripple-controlled triple-tariff meters at Versailles has only increased the undertaking's load factor by a relatively small amount. This is understandable, for it is hard to see how the installation of a triple-tariff system for ordinary consumers could improve load factor *per se*, unless the high tariff were prohibitively high. The purpose of this tariff system is perhaps more to distribute the costs of supply equitably among the consumers in accordance with the desirability of their individual loads. Such tariff systems are, however, unpopular in this country.

Mr. Orchard argues that peak control as such is undesirable. The whole question is certainly a contentious one, but Mr. Orchard would find that a large and possibly growing number of his colleagues would express the contrary view equally forcibly. It has been remarked that the cost of maximum demand is implicit in the nature of electricity, and that the encouragement of regulated off-peak loads at low tariffs cannot be said to be "restricting the use of energy." I entirely disagree with Mr. Orchard that the only use of ripple control is for street lighting, and, apropos of this, it should be pointed out that the system which Mr. Orchard

has successfully installed in his own borough is now being actively developed to provide control of all the services enumerated in my paper. Mr. Orchard refers to the unreliability of a number of fully automatic substations for which he was responsible, and believes that difficulties will be experienced in the maintenance of a ripple control equipment. Bearing in mind that such installations have been in operation for many years, there appears to be little justification for this view. Mr. Orchard also inquires whether the Maidstone Corporation investigated other systems before adopting ripple control. The answer is that, of the only two possible alternatives, the earth-return system and the d.c. bias system, the earth-return system was tested for a period of 2 years prior to the installation of ripple control, and was not adopted, and the d.c. bias system could not be applied, since a large section of the Maidstone Corporation network is itself direct-current. In addition, the individual substations are not connected to the central station by pilots.

Regarding the mechanics of tuned reeds at various frequencies, Mr. Mackenzie rather assumes that low frequencies are selected for ripple control in order to accommodate the mechanical characteristics of reeds. This is not so. Frequencies below 1 000 cycles per sec. are selected because it is found in practice that higher frequencies cannot be successfully applied on large networks, and the tuned reed has no mechanical limitations up to 1 000 cycles per sec. Mr. Mackenzie correctly observes that a reference might have been made in the paper to the balance wheel or " beat " type of relay, in which discrimination is effected by impulsing a given frequency at varying rates, and causing an armature with a hair-spring suspension to oscillate at a frequency corresponding to the frequency of the beat. Relays of this type have been known and employed for many years, but up to now they have not been found to be very reliable; nevertheless, as Mr. Mackenzie points out, the principle is well worthy of mention. In reply to his question regarding ripple frequencies, all the frequencies mentioned in the paper have been employed, and many more besides.

Regarding the employment of ripple emission by the parallel method, the principle is not always impracticable, but great caution is necessary, and when such an installation is planned it is necessary to have a fuller knowledge than is normally available of future developments of the bulk-supply connections to the network in question. This is a serious feature, for it is not possible to say to a supply authority, for example, " What will be the size and reactance of the bulk-supply transformers which you may install in 10 years' time?" Without such knowledge neither the power of the transmitter nor the frequencies to be employed can be chosen, nor can non-interference with other networks be permanently guaranteed.

This disability does not apply to the series emission system, as in this case extensions can readily be made to an existing transmitter without the necessity of increasing the power of the generator, and difficulties seldom arise if an undertaking with an existing ripple equipment decides, for example, to lay higher-voltage feeders to relieve overloaded sections of the network. There are many ripple transmitters in service which are transmitting signals on networks with feeders of three or four different h.t. distribution voltages.

Mr. Mackenzie also inquires why the magnetizing current in the emission transformers has to be compensated by capacitance. The reason is that this magnetizing current may be so large that in the absence of compensation a high-frequency alternator would have to support large wattless currents, which would increase the cost of the machine. There would also be difficulties to overcome in connection with protective and stabilizing devices which have to be incorporated in the ripple circuit.

Regarding the application to d.c. networks, with the technique employed difficulties are not experienced owing to the high inductance of the system, but there are certain types of d.c. network to which ripple control cannot be applied.

I am very interested to learn from Mr. Dykes of his pioneer experiences at Egham.

It may be that in future the balance-wheel type of relay advocated by Mr. Oliver will be developed to a satisfactory degree of reliability; it has not been widely employed in recent times owing to the difficulty of making a reliable unit at a low price. The permissible cost of a ripple reception relay has in the past ruled out a number of thoroughly feasible techniques, such as this one. Although it is becoming quite common practice to employ these relays in conjunction with ripple control schemes for applications where the cost of the relay is immaterial, I believe it will be difficult to produce a reliable relay of this type which will stand the hard usage and wide temperature-ranges associated, for example, with street-lighting control services.

Mr. McWhirter is a firm advocate of decentralized control from substations, and mentions quite correctly that there are no disadvantages in using pilot wires to link the substations to a central point. This, however, is hardly the point, for there are very few networks in this or any country in which there is an *existing* pilot to each and every substation on the network. It is possible to rent such lines from the Post Office, but if one capitalizes the annual rental the result is a strong deterrent to their employment. Equally, it seems nearly impossible to advocate that an undertaking with, say, 50 substations, should lay special pilots from a central point to each of these existing substations. In such cases it appears preferable to employ the high-voltage feeders themselves as pilots, which is in effect the function of a ripple control system.

In dealing with the application of ripple control to large city networks, Mr. McWhirter asks how long it would take to ripple 300 feeders. This question seems in the last degree academic, as I cannot conceive that there is a single generating station in the world with 300 outgoing feeders. It is rare in practice to find more than 30 outgoing feeders from a large modern station with 11-kV or 33-kV distribution.

Mr. McWhirter speaks of the lower cost of the d.c. bias system: the cost is, however, only lower if the network is small and street lighting only is to be considered. In larger networks the cost of the transmitters and pilots required is nearly always greater than the cost of a ripple control system.

Commenting on my remark that no economical method of providing multiple facilities by the d.c. bias system has been devised, Mr. McWhirter draws attention to a recent description of a multi-service d.c. bias installation. It was, however, on this description that my remarks were based, and I feel that it is not easy to contemplate the employment of the multiple-service relays there described for any applications where large numbers might be required, as their high individual cost might prohibit their use. Regarding the possibility of slot ripple on a d.c. network causing false operation of a ripple relay, this point does not arise, since the amplitude of such ripples is never sufficiently great, even in the odd chance of their frequency coinciding with that of the closely tuned relay.

In reply to Mr. Hallowell, the power necessary to operate the types of ripple relay illustrated is 0·1 watt. Mr. Hallowell's criticism that the frequencies selected approach too closely to normal harmonic frequencies is not borne out in practice, as it must be remembered that the relays are extremely closely tuned, and a separation of 15 cycles is ample.

Mr. Logan asks whether the ripple materially affects the r.m.s. value of the system voltage; as is stated in the paper, the effect is inappreciable. The answer to his question regarding the selectivity of relays at over-voltages is that selectivity and sensitivity are to a small extent proportional, and in consequence an excess voltage does widen the operating frequency-band. An increase to twice the normal voltage will widen the band of operation by about 3 % of the rated frequency of the relay. The "on" and "off" frequencies can therefore never overlap as the result of the existence of excess voltage.

In answer to Mr. Bowsher's inquiries regarding possible inductive interference, this question has had to be exhaustively investigated but no such trouble has been experienced. A ripple signal cannot be detected with an ordinary wireless set.

Dr. Stern refers to possibilities of central control installations being sabotaged, in the event of war. This seems to be in the last degree unlikely, since the equipment which would be required to interfere with a ripple control installation would be expensive, extremely difficult to obtain without exciting inquiry, and would require installation by a person of considerable technical competence. In addition, the interference provoked could not extend beyond an individual low-voltage network.

In reply to Mr. Prowse, I feel that it will often be possible to make out a good case for independent transmitters in individual substations on small networks.

Mr. Lee correctly observes that the terms "high frequency" and "audio frequency" are a little loosely used in the paper. With regard to the addition of condensers for suppressing radio interference, the effect of such condensers is quite negligible, since their individual capacitance is small.

Mr. Patmore inquires the advantage of standardizing a 3-reed type of relay where half-night lighting is employed. Such a relay is, of course, only employed at those points where three separate control operations are required, such as "on," "half off," "off," and would not be employed throughout the system for the sake of standardization only.

Regarding the effects of moisture, it is found necessary to take most careful precautions to avoid the ingress of moisture into a relay case. It is, however, quite easy to make a case entirely moisture-proof at the cost of a shilling or so per relay.

In conclusion, I feel it to be significant that the discussion is concerned only with the relative merits of the various central control systems, and that no speaker has seriously challenged the main premises of the paper. These premises may perhaps be summarized:—

(1) Superimposed control systems are technically and commercially an accomplished fact, and their future progress seems assured.

(2) The central control of street lighting by these methods offers great benefits of cost, convenience, and, in present circumstances, safety.

(3) The employment of central control for the regulation of off-peak supplies can, with the stimulus of suitable tariffs, enable consumers to use the millions of low-priced off-peak units which the supply industry would like to sell.

To improve load factor has always been a supreme commercial aim. In the domestic field the limited diversity of human habit must continue to restrain domestic load-factor from improving much beyond its present limits. These limits can be exceeded by recourse to a controlled supply to water heating, low-temperature space heating, and certain other loads. It may well be that it is chiefly in this field that centralized control will in the future exhibit its supremacy.

FIELD-POLE LEAKAGE FLUX IN SALIENT-POLE DYNAMO-ELECTRIC MACHINES*

By I. A. TERRY and PROFESSOR E. G. KELLER, M.S., Ph.D.

(*Paper first received* 20*th October*, 1937, *and in final form* 13*th April*, 1938.)

SUMMARY

In this paper the authors investigate the problem in salient-pole dynamo-electric machines of flux passing from field pole-tip to pole-tip without linking the armature winding. This flux, designated "pole-tip leakage," is of broad interest in determining both transient and steady-state performance characteristics of salient-pole dynamo-electric machines.

The problem is treated as one of two dimensions and the method of conformal transformation is used to obtain results in the form of elliptic functions. Numerical results are obtained by a method of cross-plotting and given in curve form for the usual range of variables. The curves have been used in the design of machines for 5 years, and the great number of test-results obtained have been found to be in very satisfactory agreement with the calculations.

(1) INTRODUCTION AND SCOPE

The flux which passes from pole to pole of a salient-pole dynamo-electric machine without linking the armature winding is known as field-pole leakage flux. This leakage flux determines the field leakage-reactance, which is of interest in determining the starting and, more generally, transient performance characteristics of salient-pole synchronous machines. The leakage flux is also used in determining the excitation requirements of salient-pole dynamo-electric machines under steady-state conditions. An accurate determination of this quantity is obviously essential to the designer of such machines, for the proper proportioning of materials to meet most effectively all operating conditions, with minimum allowances for deviation between calculated and test results.

The leakage flux arises essentially as a result of the magnetomotive-force (m.m.f.) and permeance between the poles themselves, being sensibly independent of armature m.m.f. Fig. 1 shows a typical configuration of a salient-pole synchronous machine. There are indicated permeances associated with five components of leakage flux in addition to that of the useful flux permeance Ψ_u. The configuration of Fig. 1 is not amenable to analytical treatment, but simplifications can be made which introduce errors of negligible consequence. The pole-tip leakage permeance Ψ_1 is the subject of the present investigation. The pole-body leakage permeance Ψ_2 can be obtained with sufficient accuracy by considering the flux to go straight across from pole to pole.† The leakage permeances Ψ_3 and Ψ_4, between the pole ends and the spider and stator respectively, are so small in comparison with others that only minor errors are introduced by neglecting them entirely. The leakage permeance Ψ_5 between adjacent pole-ends can be obtained from an adaptation of Fig. 3 of Reference (2) in the Bibliography.

By assuming the pole bodies to be parallel and of infinite permeability, the air-gap to be uniform and of infinite extent, all boundary lines straight, and all corners right-angles, Fig. 1 can be replaced by Fig. 2. Then Ψ_1, the pole-tip leakage permeance, can be determined, by means of conformal transformations, as that included between the flux line which passes through $\xi = -1$ and the flux line which passes through $\xi = a$. Flux in the region $\xi < -1$ is useful and is determined by Ψ_u. Flux in the region $0 < \xi < a$ is pole-body leakage, determined by Ψ_2.

With certain proportions of the boundaries not usually met in practical cases, the two limiting lines $\xi = -1$ and $\xi = a$ become coincident, or the flux line passing from

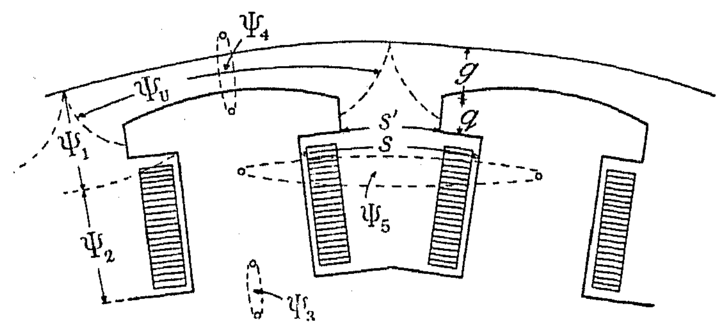

Fig. 1.—Field pole of a typical salient-pole synchronous machine, showing permeances ψ_n associated with useful and leakage fluxes.

$\xi = -1$ may even enter the side of the pole below $\xi = a$. In this case all the flux issuing from the pole tip (including the under-side of it, and some below) enters the armature surface as useful flux. Ψ_1 then becomes negative, subtracting from the pole-body permeance Ψ_2, which now is less accurately determined by assuming the flux to go straight across.

(2) GENERAL DESCRIPTION OF THE MATHEMATICAL ANALYSIS AND METHODS OF OBTAINING RESULTS

The mathematical analysis for determining the pole-tip leakage permeance is given in the Appendix. Only a general description of the processes employed, including the methods of obtaining the numerical results, is given at this point.

A continuous function $\Phi(x, y)$, with continuous first partial derivatives, which reduces to prescribed values on

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† See Bibliography, (1).

the boundary of a region in the xy-plane and satisfies Laplace's equation, namely

$$\frac{\partial^2\Phi}{\partial x^2}+\frac{\partial^2\Phi}{\partial y^2}=0$$

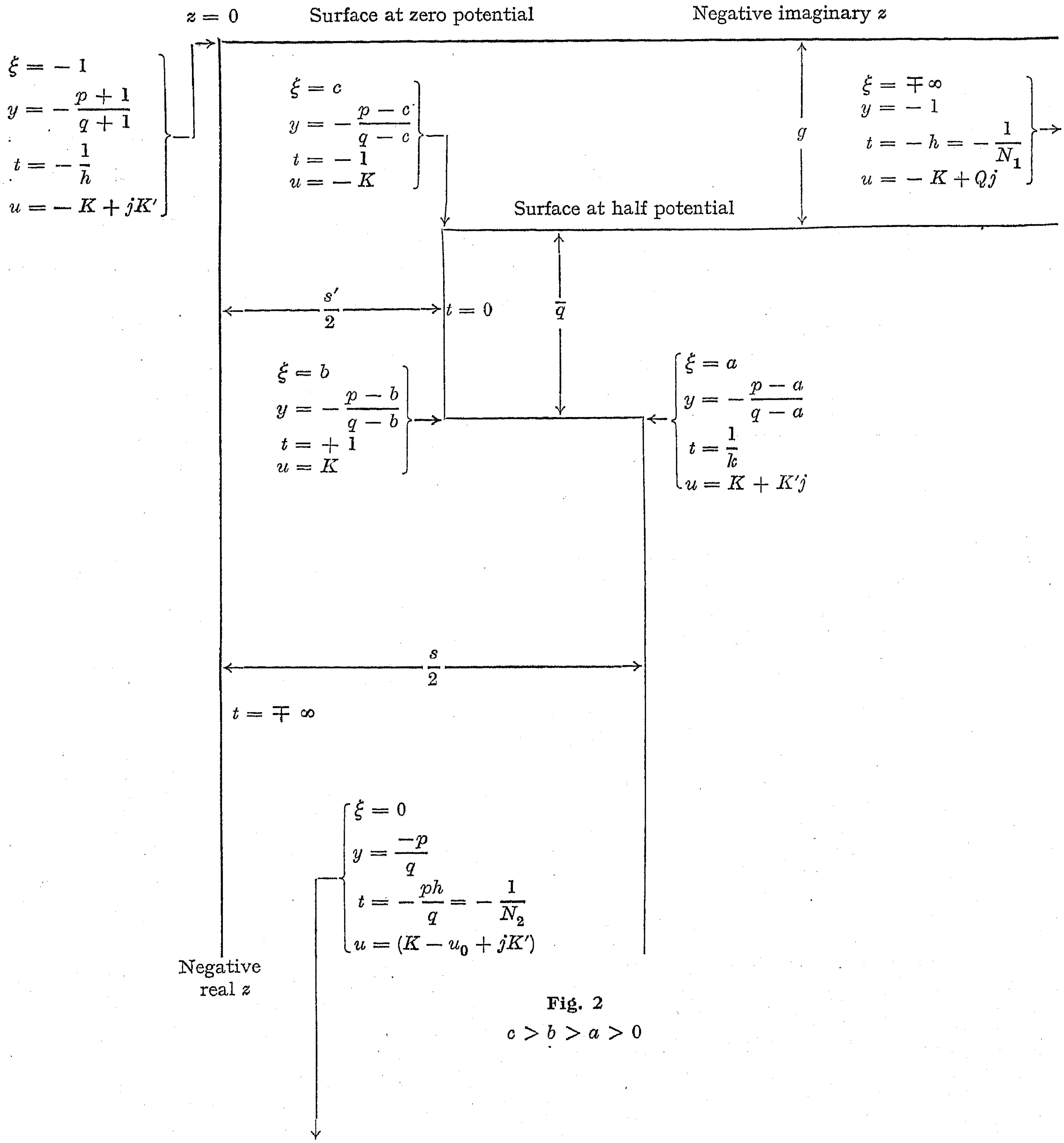

Fig. 2
$c > b > a > 0$

is a potential function. If the magnetic potential is specified along the boundary, then Φ is the magnetic potential. The mathematical objective of this investigation is to obtain, for the interior of Fig. 2, the flux function $\Psi(x, y)$ associated, by means of the Cauchy–Riemann partial differential equations, with Φ.

In the present problem the north-pole surface, represented in Fig. 2 by the straight lines from $\xi = \infty$ to c, $\xi = c$ to b, $\xi = b$ to a, and $\xi = a$ to 0, is taken to be at magnetic potential $+\frac{1}{2}$. The line midway between a north and a south pole from $\xi = 0$ to $\xi = -1$ and the armature surface from $\xi = -1$ to $\xi = -\infty$ are at potential zero. It is required then to find a function Φ

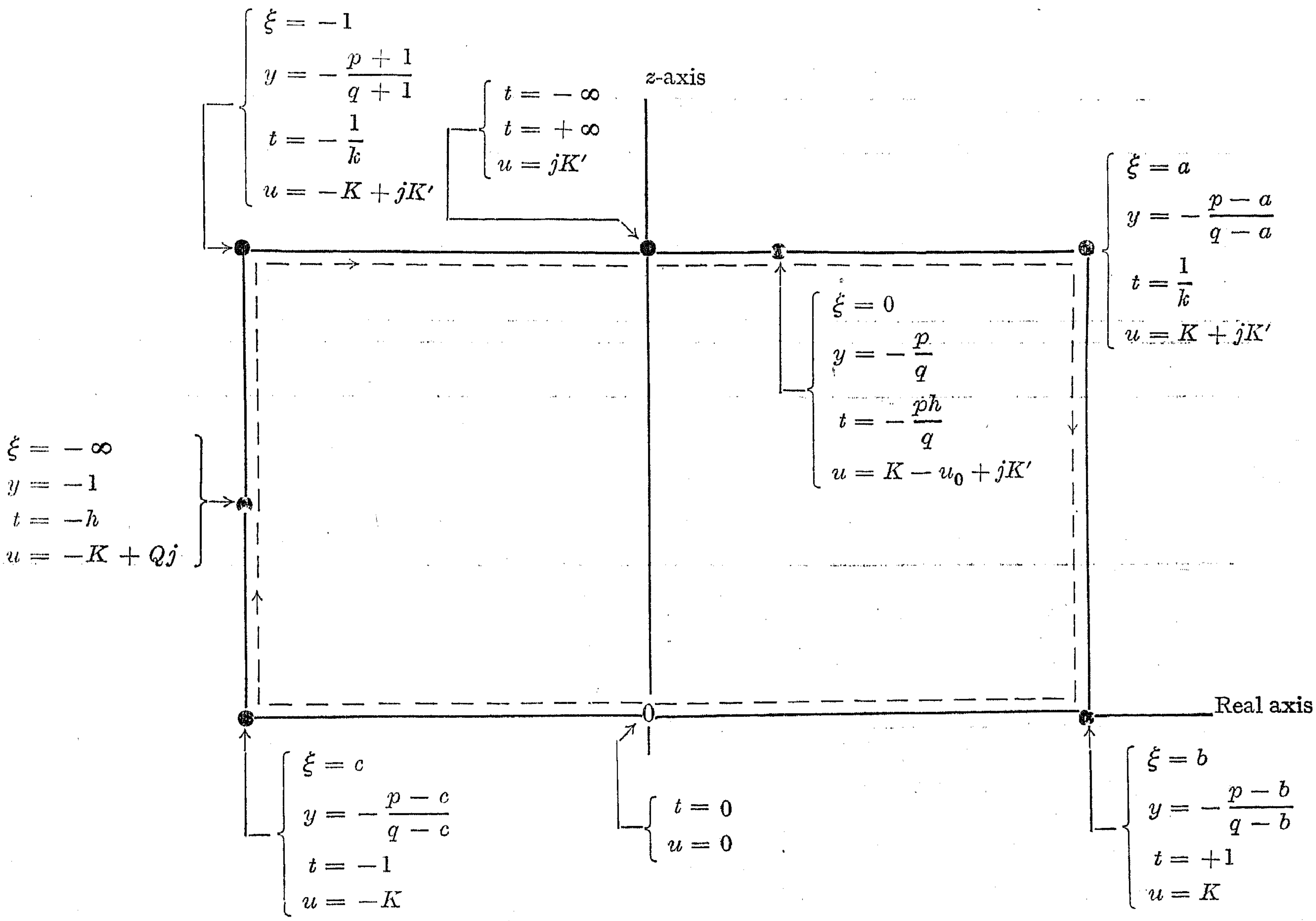

Fig. 3

which satisfies Laplace's equation within the contour and reduces on the boundary to the values just described.

From the theory of functions of a complex variable it is known that in the functional relation

$$W \equiv \Phi(x, y) + j\Psi(x, y) = f(z)$$

which maps a region of the z-plane on to a region of the W-plane, both $\Phi(x, y)$ and $\Psi(x, y)$ satisfy Laplace's equation provided $f(z)$ is an analytic function.

By the well-known theorem of Schwarz and Christoffel a transformation $W = f(z)$ can be found which transforms the contour and non-uniform field of Fig. 2 into the uniform field of Fig. 4. This is not accomplished in one step. Instead the field in the z-plane (Fig. 2) is transformed on to the real axis of the intermediate ξ-plane (Fig. 4). Likewise the uniform field of Fig. 4 is transformed on the real axis of the same ξ-plane. Thus, through the intermediate variable ξ, W is obtained as a function of z.

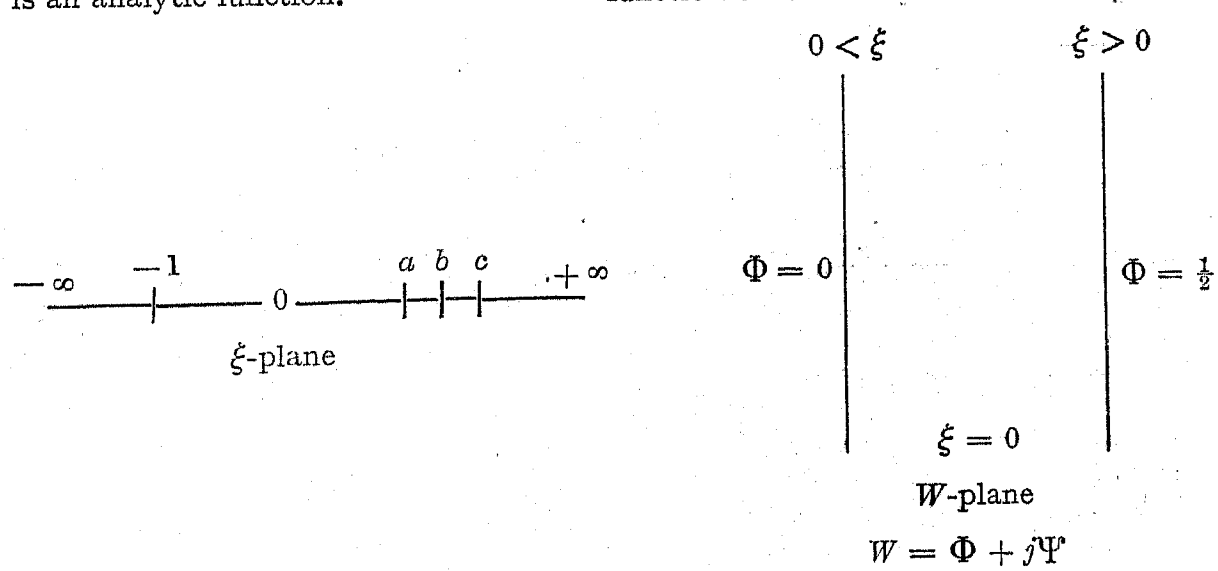

Fig. 4

Table

VALUES COMPUTED ON THE ASSUMPTION THAT $s/(2g) = 10$ AND $a = 0{\cdot}05$

b	c	k	K_1	K_2	K_3	Q	u_0	$sn(Q)$	$sn(u_0)$	$Z(Q)$
0·075	66·66	0·73	8·2	− 0·08	17·2	0·28	1·30	0·29	0·92	0·079
0·1	50	0·64	6·1	− 0·008	8·92	0·09	1·1	0·09	0·86	0·017
0·125	40	0·57	5·23	− 0·112	7·65	0·24	0·91	0·23	0·91	0·02
0·15	33·33	0·49	4·95	− 0·16	7·9	0·21	0·75	0·22	0·75	0·02

$Z(u_0)$	q_1	q_2	q_3	q_4	s_1	s_2	s_3	$s'/(2g)$	q/g
0·11	29·9	0·059	− 14	− 1·92	30	0·10	− 26·1	12	14
0·10	21·9	0	− 11	− 0·46	22·8	0	− 24·8	9·02	10·9
0·09	18·2	− 0·23	− 11·2	− 2	22	− 0·31	− 32	5·24	3·5
0·066	16·1	0	− 11·2	− 3·4	21·6	0·09	− 33·6	4	1·5

The Schwarzian transformation mapping the configuration in the z-plane on to the ξ-plane is defined by equation (1) (see Appendix), namely

$$\frac{dz}{d\xi} = \frac{A(\xi - b)^{\frac{1}{2}}(\xi - c)^{\frac{1}{2}}}{\xi(\xi + 1)^{\frac{1}{2}}(\xi - a)^{\frac{1}{2}}} \quad . \quad . \quad . \quad (1)$$

in which the parameters A, a, b, c, give different relative dimensions and orientations of the contour in the z-plane relative to the real axis of the ξ-plane. The problem is to express the relative dimensions and orientations in terms of the parameters. Since the contour of Fig. 2 is unsymmetrical, the elliptic integrals resulting from equation (1) are reduced to standard forms by means of the usual Legendre transformations.

The fundamental ratios of the problem are q/g, $s/(2g)$, and $s'/(2g)$. These ratios in terms of a, b, c are given by the equations*

$$\frac{s}{2g} = \sqrt{\left(\frac{bc}{a}\right)}$$

and

$$q = 2\overline{K}_1 K + \frac{2\overline{K}_2 K}{cn\,\alpha\,dn\,\alpha} Z(\alpha) + \frac{2\overline{K}_3 K}{cn\,\beta\,dn\,\beta} Z(\beta) + \frac{\overline{K}_2 \log(-1)}{cn\,\alpha\,dn\,\alpha} + \frac{\overline{K}_3 \log(-1)}{cn\,\beta\,dn\,\beta} \quad . \quad . \quad (9)$$

$$\left(\frac{s' - s}{2}\right) = \overline{K}_1 K' + \frac{\overline{K}_2 K'}{cn\,\alpha\,dn\,\alpha} Z(\alpha) + \frac{\overline{K}_3 K'}{cn\,\beta\,dn\,\beta} Z(\beta) + \frac{\pi \overline{K}_2}{2\,cn\,\alpha\,dn\,\alpha}\left(1 + \frac{\alpha}{K}\right) + \frac{\pi \overline{K}_3}{2\,cn\,\beta\,dn\,\beta}\left(1 + \frac{\beta}{K}\right). \quad (12)$$

where the constants $\overline{K}_1$, $\overline{K}_2$, $\overline{K}_3$ and the parameters α, β are defined by equations (4) and (5) respectively, in Section (a) of the Appendix. On attempting to pass to numerical results it is observed that the parameters α and β are such that $sn\,\alpha$ and $sn\,\beta$ exceed unity in value. Consequently α and β are complex quantities and equations (9) and (12) must be reduced to a form where the quantities are real to be suitable for numerical calculations. The desired relations are given in equations (16) and (17) (see Appendix).

* Natural logarithms are employed throughout this paper.

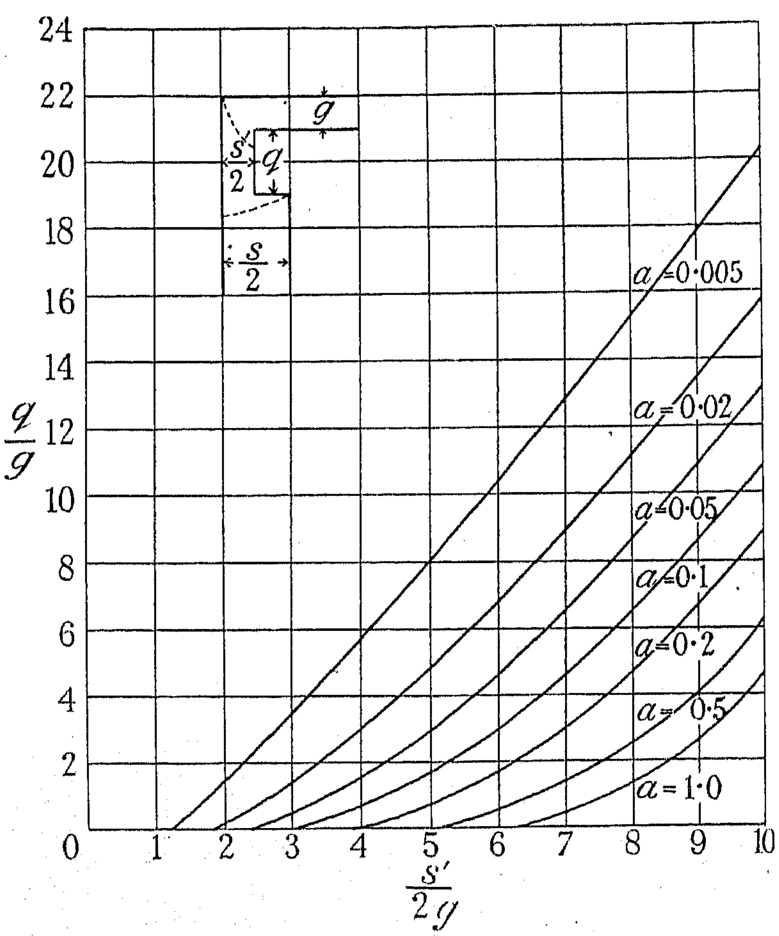

Fig. 5.—Curves for calculating pole-tip flux leakage for $s/(2g) = 10$.

$\frac{1}{2\pi}$ log a gives flux in c.g.s. units between dotted lines in inset diagram for potential difference of $\frac{1}{2}$.

The Schwarz–Christoffel transformation mapping the W-plane on to the ξ-plane is

$$W = \Phi + j\Psi = \frac{j}{2\pi}(\log|\xi| + j\theta) + \text{constant} \quad (19)$$

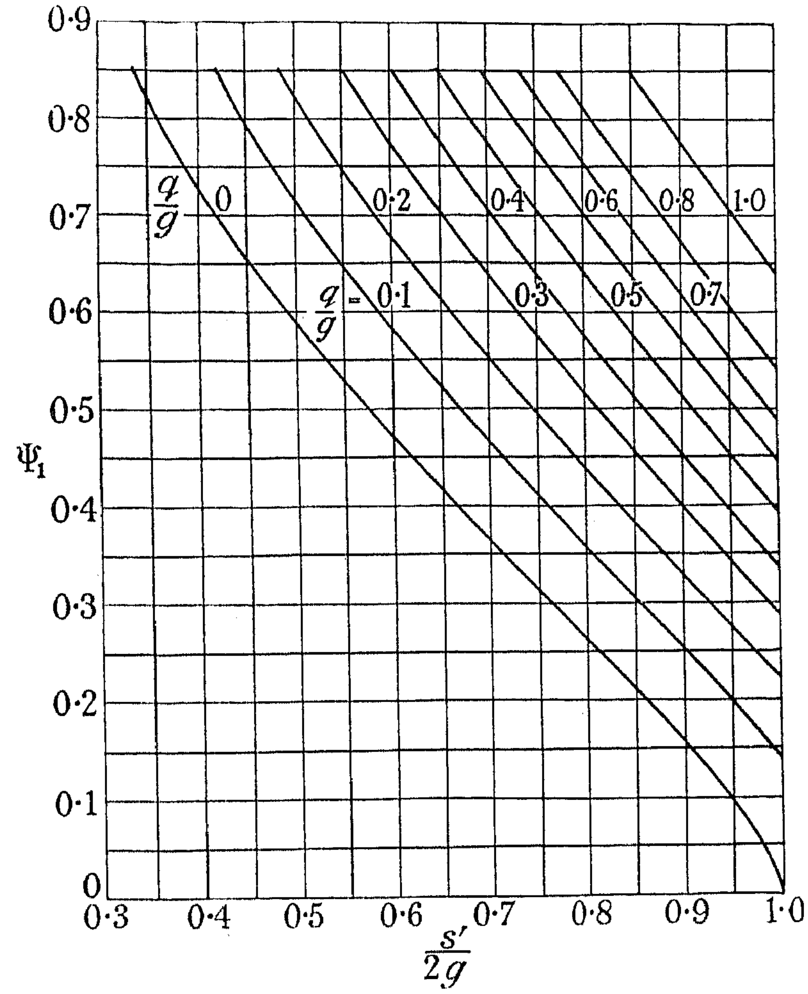

Fig. 6.—Pole-tip flux leakage factor for $s/(2g) = 1$.

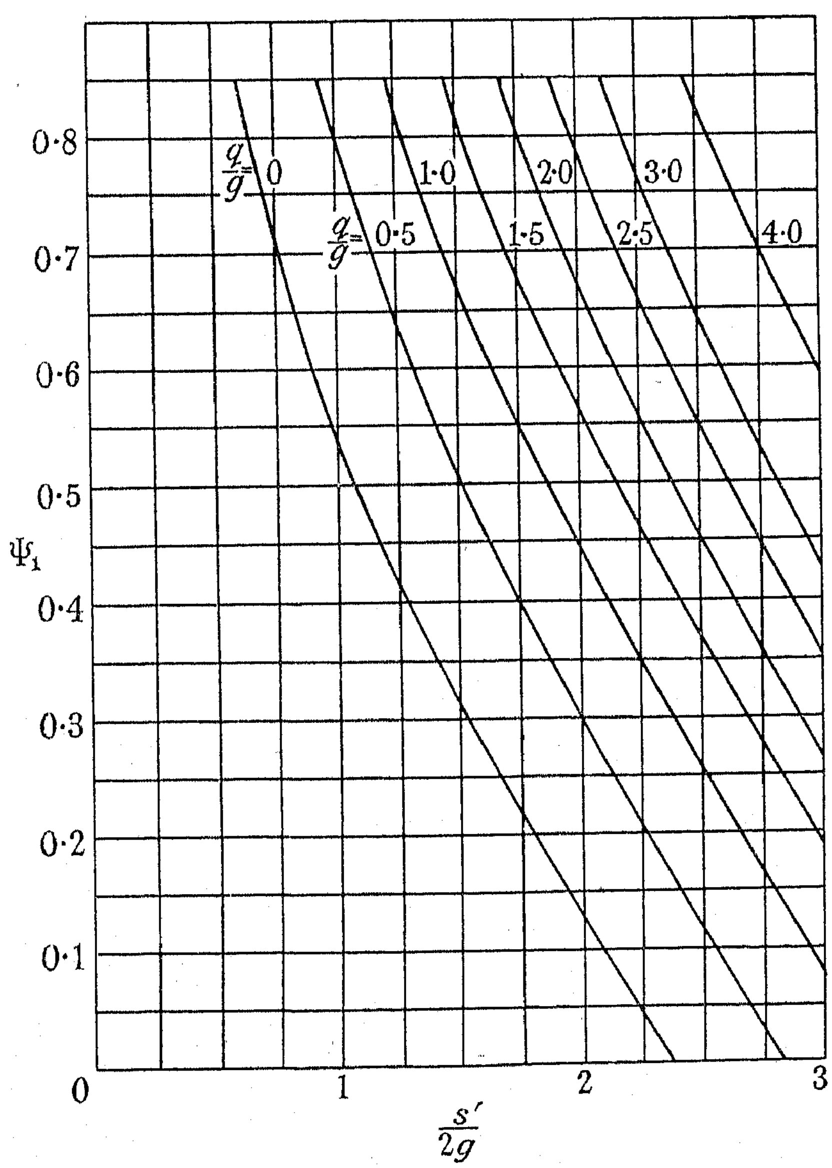

Fig. 7.—Pole-tip flux leakage factor for $s/(2g) = 3$.

where Φ is the potential function and Ψ is the flux function. The line of zero flux is, of course, arbitrary. In this investigation the line of zero flux is taken to correspond to $\xi = -1$. So by evaluating equation (19) between the limits $\xi = -1$ and $\xi = a$, and equating real and imaginary quantities, the expression

$$\Psi_1 = \frac{1}{2\pi} \log a$$

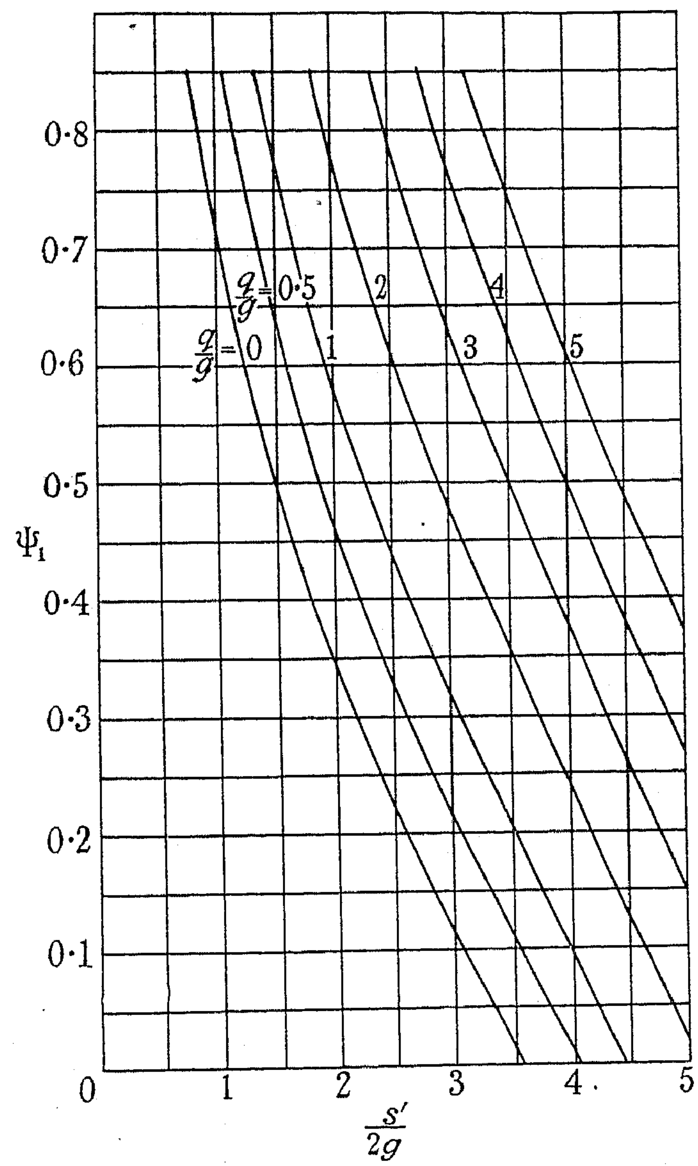

Fig. 8.—Pole-tip flux leakage factor for $s/2g = 5$.

is obtained for the permeance associated with the pole-tip leakage flux.

In using the fundamental formulae

$$\frac{s}{2g} = \sqrt{\left(\frac{bc}{a}\right)}, \quad \Psi_1 = \frac{1}{2\pi} \log a$$

and equations (16) and (17), the values of $s/(2g)$ and a are assumed and the values of b and c which produce ratios of $s'/(2g)$ and q/g applicable to commercial machines are found by trial substitution. For example, by substitution of $a = 0 \cdot 05$, $b = 0 \cdot 1$ in the relation

$$\frac{s}{2g} = \sqrt{\left(\frac{bc}{a}\right)} = 10$$

c is found to be 50. Substitution of these values in equations (16) and (17) yields $s'/(2g) = 9 \cdot 02$ and $q/g = 10 \cdot 9$. The Table gives detailed computations for the line $a = 0 \cdot 05$ in Fig. 5. In the Table the four terms

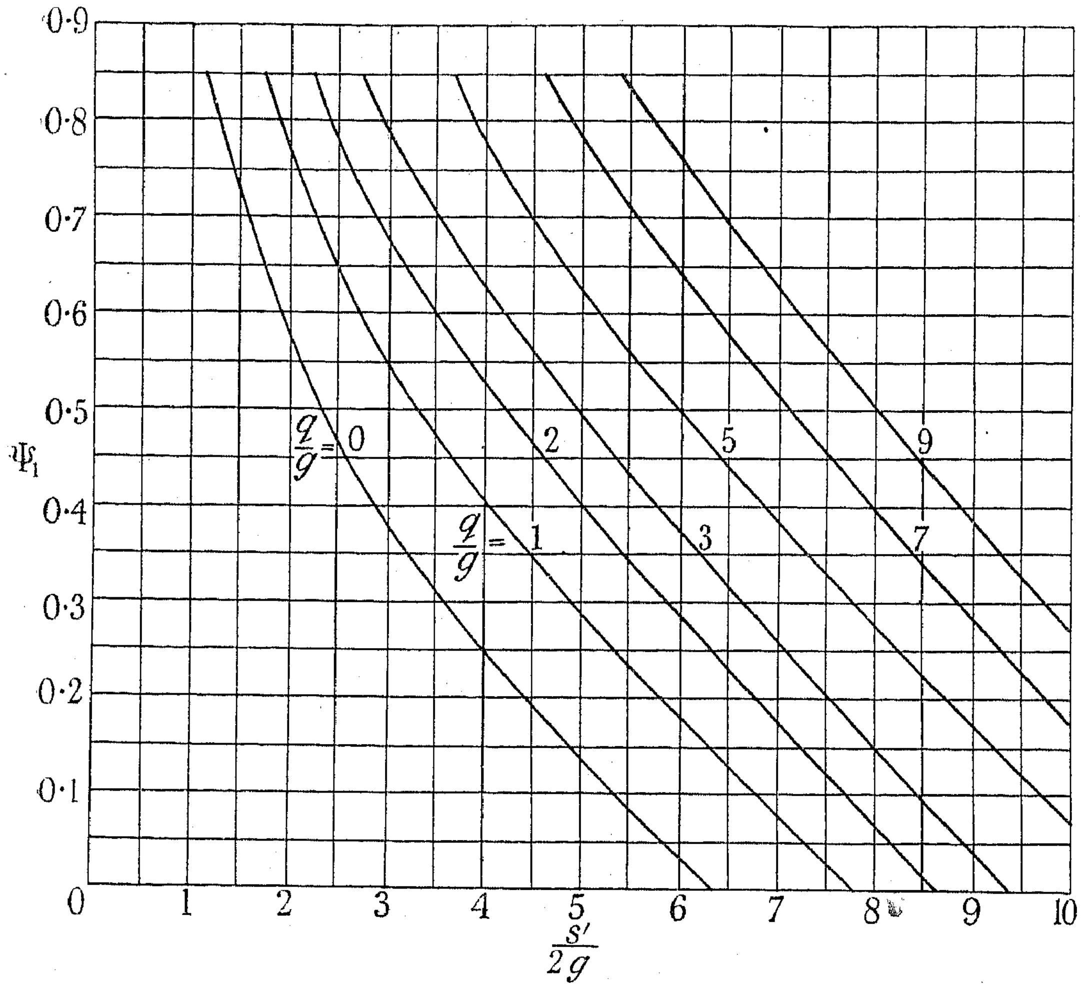

Fig. 9.—Pole-tip flux leakage factor for $s/(2g) = 10$.

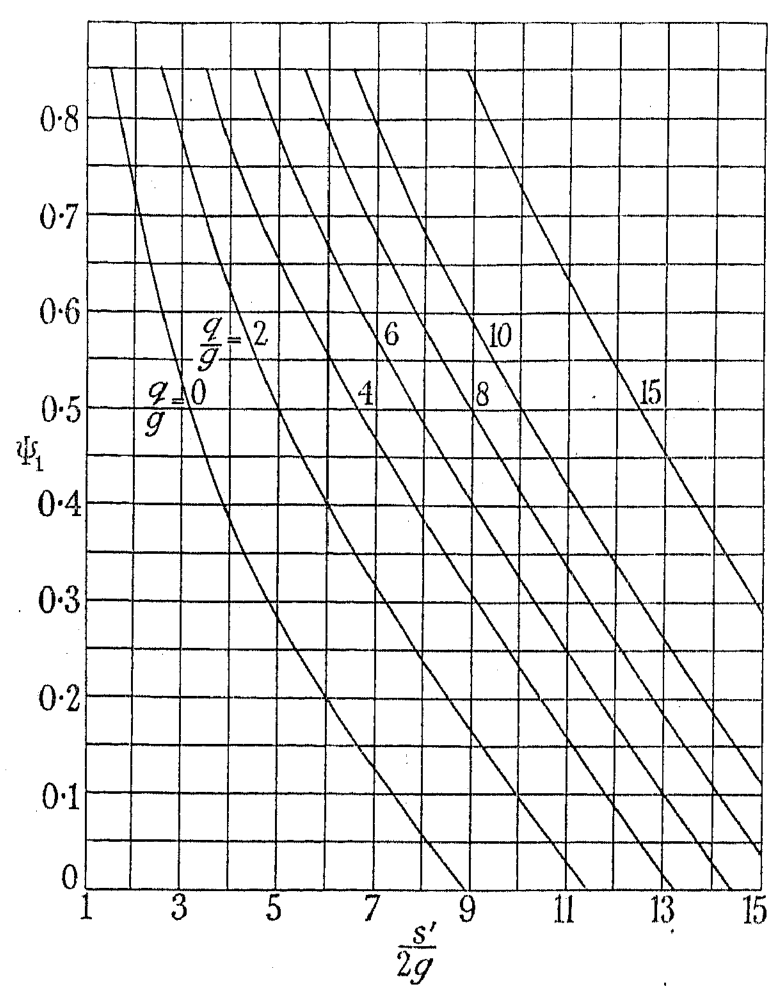

Fig. 10.—Pole-tip flux leakage factor for $s/(2g) = 15$.

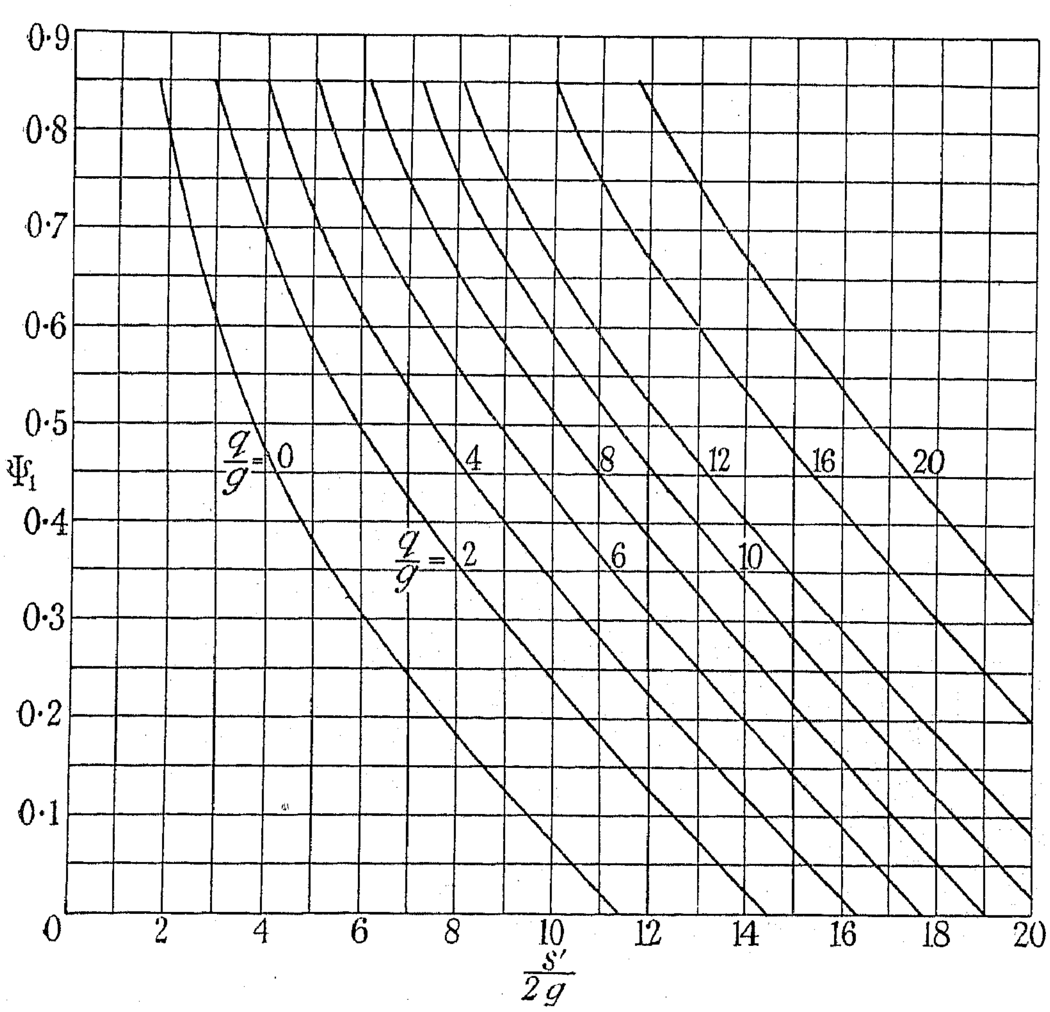

Fig. 11.—Pole-tip flux leakage factor for $s/(2g) = 20$.

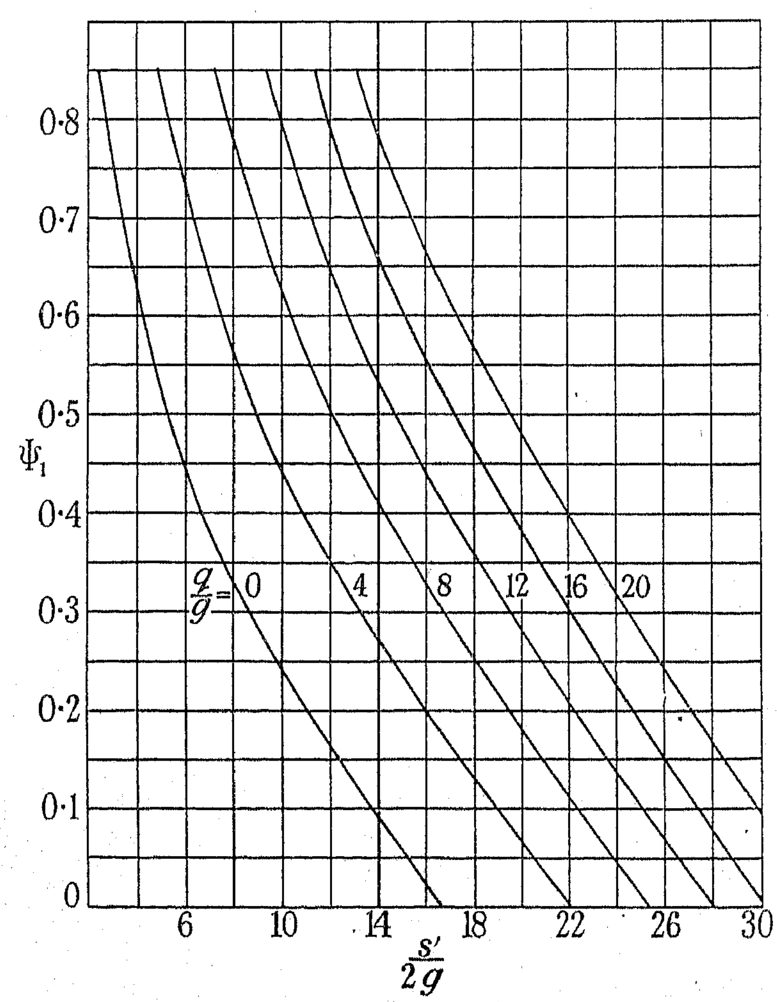

Fig. 12.—Pole-tip flux leakage factor for $s/(2g) = 30$.

of the right member of equation (16) are denoted by q_1, q_2, q_3, q_4, and the three terms of the right member of equation (17) by s_1, s_2, s_3.

The end points of the curves in Fig. 5 corresponding in the one case to the degeneration of the pole-tip height q to 0, and in the other case to making $s' = s$, were also obtained from Carter's consideration of Fig. 31 in Reference (7) of the Bibliography.

(3) RESULTS, AND THEIR APPLICATION IN DESIGN

The nomenclature pertaining to the application of the results in practical cases is as follows:—

Ψ'_1 = pole-tip leakage permeance (from Figs. 6 to 12);
F = ampere-turns per pole at tip;
g = radial air-gap (assumed uniform and equal to that existing at corner or tip of pole);
q = height of pole tip at outside, neglecting rounding of corners;
s = distance between pole-sides at junction with tip;
and s' = distance between pole-tips (taken up $q/2$ from under-side of tip).

Application of the results to salient-pole dynamo-electric machines requires a means of evaluating the leakage permeance Ψ'_1 directly. Since it is a function of three parameters $s'/(2g)$, $s/(2g)$, and q/g, a table of values is not convenient. Consequently sets of curves like Fig. 5 were obtained for $s/(2g) = 1, 3, 5, 10, 15, 20$, and 30, and for $a = 1$, $0\cdot5$, $0\cdot2$, $0\cdot05$, $0\cdot02$, and $0\cdot005$, taking b arbitrarily greater than a, and completing c from the relation

$$\frac{s}{2g} = \sqrt{\left(\frac{bc}{a}\right)}$$

By reference to Fig. 5 it is evident that the results can be expressed in a more readily usable form by plotting Ψ'_1 as a function of $s'/(2g)$ and q/g for various values of $s/(2g)$. Accordingly, the data of Fig. 5 were cross-plotted, yielding Fig. 9. Figs. 6 to 12 were all obtained in the same manner.

In the practical case where the poles are alternately north and south, and each has an m.m.f. at the tips of F ampere-turns, the pole-tip leakage flux per pole per centimetre axial length is given by $1\cdot6\pi F\Psi'_1$.

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APPENDIX

Mathematical Analysis

It is desired to transform the field (and contour) shown in Fig. 2 in the z-plane to a uniform field in the W-plane shown in Fig. 4. This transformation is accomplished, in the usual manner, by transforming the fields in the z-plane and the W-plane to the intermediate ξ-plane shown in Fig. 4. In the course of evaluating the ratios $\bar{q}/g$ and $s/(2g)$ auxiliary planes t, y, and u appear; these are due to successive changes of independent variable. The u-plane is shown in Fig. 3.

(a) Transformation from the z-plane to the ξ-plane.

By reference to Fig. 2 and the Schwarzian theorem, the transformation from the z-plane to the ξ-plane is seen to be

$$\frac{dz}{d\xi} = \frac{A(\xi - b)^{\frac{1}{2}}(\xi - c)^{\frac{1}{2}}}{\xi(\xi + 1)^{\frac{1}{2}}(\xi - a)^{\frac{1}{2}}} \quad . \quad . \quad . \quad (1)$$

Equation (1), under the change of variable $\xi = (p + qy)/(1 + y)$, reduces to

$$z = \frac{A(q-p)(q-b)(q-c)}{q(B_1B_2)^{\frac{1}{2}}}\int\frac{dy}{[(1-g^2y^2)(1-h^2y^2)]^{\frac{1}{2}}}$$
$$+\frac{A(M-N)}{(B_1B_2)^{\frac{1}{2}}}\int\frac{dy}{(1+y)[(1-g^2y^2)(1-h^2y^2)]^{\frac{1}{2}}}$$
$$-\frac{A(Mp-Nq)}{q(B_1B_2)^{\frac{1}{2}}}\int\frac{dy}{\left(\frac{p}{q}+y\right)[1-g^2y^2)(1-h^2y^2)]^{\frac{1}{2}}} \quad (2)$$

where

$$p = S_1 + S_2, \quad q = S_1 - S_2$$
$$S_1 = \frac{a+bc}{c+b+1-a}, \quad S_2 = \frac{[(1+b)(1+c)(a-b)(a-c)]^{\frac{1}{2}}}{c+b+1-a}$$
$$A_1 = -(q+1)(q-a), \quad B_1 = (p+1)(p-a)$$
$$A_2 = -(q-b)(q-c), \quad B_2 = (p-b)(p-c)$$
$$M = (q-b)(p-c) + (p-b)(q-c) - \frac{(p+q)(q-b)(q-c)}{q}$$
$$N = (p-b)(p-c) - \frac{p}{q}(q-b)(q-c)$$
$$(q-b)(p-c) + (p-b)(q-c) \equiv 0$$

Equation (2), under the change of variable $hy = t$, reduces to

$$z = \overline{K}_1\int\frac{dt}{[(1-t^2)(1-k^2t^2)]^{\frac{1}{2}}} + \overline{K}_2\sqrt{\left(\frac{B_2}{A_2}\right)}\int\frac{dt}{(1+N_1t)[(1-t^2)(1-k^2t^2)]^{\frac{1}{2}}} + \frac{\overline{K}_3q}{p}\sqrt{\left(\frac{B_2}{A_2}\right)}\int\frac{dt}{(1+N_2t)[(1-t^2)(1-k^2t^2)]^{\frac{1}{2}}} \quad (3)$$

where $N_1 = \sqrt{(B_2/A_2)}$, $N_2 = \frac{q}{p}\sqrt{(B_2/A_2)}$

$$\overline{K}_1 = \frac{A(q-p)(q-b)(q-c)}{q\sqrt{(B_1A_2)}}, \quad \overline{K}_2 = \frac{A(M-N)}{\sqrt{(B_1B_2)}} \quad . \quad (4)$$

$$\overline{K}_3 = \frac{A(Nq-Mp)}{q\sqrt{(B_1B_2)}}, \quad k^2 = \frac{A_1B_2}{B_1A_2}$$

By the elliptic transformation $t = sn\,u$, equation (3) becomes

$$z = \overline{K}_1\int du + \overline{K}_2\int\frac{du}{sn\,u - sn\,\alpha} + \overline{K}_3\int\frac{du}{sn\,u - sn\,\beta} \quad . \quad (5)$$

where

$$sn\,\alpha = -\frac{1}{N_1} < 0, \quad sn\,\beta = -\frac{1}{N_2} > 0$$

Performing the integrations indicated in equation (5), we obtain

$$z = \overline{K}_1u + \frac{\overline{K}_2}{cn\,\alpha\,dn\,\alpha}\left[uZ(\alpha) + \log\frac{\vartheta_1\left(\frac{u-\alpha}{4K}\right)\vartheta_4\left(\frac{u-\alpha}{4K}\right)}{\vartheta_2\left(\frac{u+\alpha}{4K}\right)\vartheta_3\left(\frac{u+\alpha}{4K}\right)}\right] + \frac{\overline{K}_3}{cn\,\beta\,dn\,\beta}\left[uZ(\beta) + \log\frac{\vartheta_1\left(\frac{u-\beta}{4K}\right)\vartheta_4\left(\frac{u-\beta}{4K}\right)}{\vartheta_2\left(\frac{u+\beta}{4K}\right)\vartheta_3\left(\frac{u+\beta}{4K}\right)}\right] + \text{Constant} \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

where the elliptic, zeta (Z), and theta (ϑ_j) functions employed are those of Jacobi, and all functions are of modulus k.

By means of equation (1), on integrating dz between the limits 0 and g and $\xi = R\epsilon^{j\theta}$ on an indefinitely large semi-circle (centre $\xi = 0$) in the upper-half ξ-plane between the limits $\theta = \pi$ and $\theta = 0$, the value of A in equation (4) is found to be gj/π. In a similar manner, by integrating on a small semi-circle (centre $\xi = 0$) in the upper-half ξ-plane the relation

$$\frac{s}{2g} = \sqrt{\left(\frac{bc}{a}\right)}$$

is obtained.

(b) Gap width and pole-tip length.

We now obtain expressions for $(s - s')/(2g)$ and $\bar{q}/g$ (see Fig. 2) in terms of elliptic, zeta, and theta functions which in turn are functions of the constants a, b, c.

Referring to Fig. 2, we note that as ξ varies from b to c (i.e. u from $+K$ to $-K$), z increases by $\bar{q}$, and consequently:—

$$\bar{q} = 2\overline{K}_1K + \frac{\overline{K}_2}{cn\,\alpha\,dn\,\alpha}\left[2KZ(\alpha) + \log\frac{\vartheta_1\left(\frac{K-\alpha}{4K}\right)\vartheta_4\left(\frac{K-\alpha}{4K}\right)}{\vartheta_2\left(\frac{K+\alpha}{4K}\right)\vartheta_3\left(\frac{K+\alpha}{4K}\right)}\right] + \frac{\overline{K}_3}{cn\,\beta\,dn\,\beta}\left[2KZ(\beta) + \log\frac{\vartheta_1\left(\frac{K-\beta}{4K}\right)\vartheta_4\left(\frac{K-\beta}{4K}\right)}{\vartheta_2\left(\frac{K+\beta}{4K}\right)\vartheta_3\left(\frac{K+\beta}{4K}\right)}\right]$$
$$- \frac{\overline{K}_2}{cn\,\alpha\,dn\,\alpha}\left[\log\frac{\vartheta_1\left(\frac{-K-\alpha}{4K}\right)\vartheta_4\left(\frac{-K-\alpha}{4K}\right)}{\vartheta_2\left(\frac{-K+\alpha}{4K}\right)\vartheta_3\left(\frac{-K+\alpha}{4K}\right)}\right] - \frac{\overline{K}_3}{cn\,\beta\,dn\,\beta}\left[\log\frac{\vartheta_1\left(\frac{-K-\beta}{4K}\right)\vartheta_4\left(\frac{-K-\beta}{4K}\right)}{\vartheta_2\left(\frac{-K+\beta}{4K}\right)\vartheta_3\left(\frac{-K+\beta}{4K}\right)}\right] \quad . \quad (7)$$

Letting

$$\frac{-K-\alpha}{4K} = v, \quad \frac{-K-\beta}{4K} = w$$

and employing the relations

$\vartheta_1(-v) = -\vartheta_1(v)$, $\vartheta_2(-v) = \vartheta_2(v)$, $\vartheta_3(-v) = \vartheta_3(v)$, $\vartheta_4(-v) = \vartheta_4(v)$ and

$$\left.\begin{aligned}\vartheta_1(v+\tfrac{1}{2}) &= \vartheta_2(v)\\ \vartheta_2(v+\tfrac{1}{2}) &= -\vartheta_1(v)\\ \vartheta_3(v+\tfrac{1}{2}) &= \vartheta_4(v)\\ \vartheta_4(v+\tfrac{1}{2}) &= \vartheta_3(v)\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (8)$$

we reduce equation (7) to

$$\bar{q} = 2\overline{K}_1K + \frac{2\overline{K}_2K}{cn\,\alpha\,dn\,\alpha}Z(\alpha) + \frac{2\overline{K}_3K}{cn\,\beta\,dn\,\beta}Z(\beta) + \frac{\overline{K}_2\log(-1)}{cn\,\alpha\,dn\,\alpha} + \frac{\overline{K}_3\log(-1)}{cn\,\beta\,dn\,\beta} \quad . \quad (9)$$

In a similar manner (limits $u = K$ and $u = K + jK'$) the equation

$$\left(\frac{s'-s}{2}\right)j = \overline{K}_1(K+jK') + \frac{\overline{K}_2(K+jK')}{cn\,\alpha\,dn\,\alpha}Z(\alpha) + \frac{\overline{K}_3(K+jK')}{cn\,\beta\,dn\,\beta}Z(\beta)$$
$$+ \frac{\overline{K}_2}{cn\,\alpha\,dn\,\alpha}\log\frac{\vartheta_1\left(\frac{K+jK'-\alpha}{4K}\right)\vartheta_4\left(\frac{K+jK'-\alpha}{4K}\right)}{\vartheta_2\left(\frac{K+jK'+\alpha}{4K}\right)\vartheta_3\left(\frac{K+jK'+\alpha}{4K}\right)} + \frac{\overline{K}_3}{cn\,\beta\,dn\,\beta}\log\frac{\vartheta_1\left(\frac{K+jK'-\beta}{4K}\right)\vartheta_4\left(\frac{K+jK'-\beta}{4K}\right)}{\vartheta_2\left(\frac{K+jK'+\beta}{4K}\right)\vartheta_3\left(\frac{K+jK'+\beta}{4K}\right)}$$
$$- \overline{K}_1(K) - \frac{\overline{K}_2(K)}{cn\,\alpha\,dn\,\alpha}Z(\alpha) - \frac{\overline{K}_3(K)}{cn\,\beta\,dn\,\beta}Z(\beta)$$

$$-\frac{\overline{K}_2}{cn\,\alpha\,dn\,\alpha}\log\frac{\vartheta_1\left(\frac{K-\alpha}{4K}\right)\vartheta_4\left(\frac{K-\alpha}{4K}\right)}{\vartheta_2\left(\frac{K+\alpha}{4K}\right)\vartheta_3\left(\frac{K+\alpha}{4K}\right)}$$

$$-\frac{\overline{K}_3}{cn\,\beta\,dn\,\beta}\log\frac{\vartheta_1\left(\frac{K-\beta}{4K}\right)\vartheta_4\left(\frac{K-\beta}{4K}\right)}{\vartheta_2\left(\frac{K+\beta}{4K}\right)\vartheta_3\left(\frac{K+\beta}{4K}\right)} \quad . \quad . \quad (10)$$

is obtained.

Letting

$$\frac{\alpha}{4K}+\frac{1}{4}+\frac{\tau}{4}=v+\frac{1}{2},\quad \frac{\beta}{4K}-\frac{1}{4}-\frac{\tau}{4}=w$$

and employing equations (8) and the additional well-known relations:—

$$\left.\begin{aligned}\vartheta_1\left(v+\frac{1+\tau}{2}\right)&=B\vartheta_3(v)\\ \vartheta_2\left(v+\frac{1+\tau}{2}\right)&=-jB\vartheta_4(v)\\ \vartheta_3\left(v+\frac{1+\tau}{2}\right)&=jB\vartheta_1(v)\\ \vartheta_4\left(v+\frac{1+\tau}{2}\right)&=B\vartheta_2(v)\end{aligned}\right\} \quad . \quad . \quad . \quad (11)$$

where

$$B=q^{-\frac{1}{4}}\epsilon^{-j\pi v}$$
$$C=q^{-\frac{1}{4}}\epsilon^{-j\pi w}$$
$$q=\epsilon^{-\frac{K'}{K}\pi}$$
$$\tau=\frac{jK'}{K}$$

we reduce equation (10) to

$$\left(\frac{s'-s}{2}\right)=\overline{K}_1K+\frac{\overline{K}_2K'}{cn\,\alpha\,dn\,\alpha}Z(\alpha)+\frac{\overline{K}_3K'}{cn\,\beta\,dn\,\beta}Z(\beta)$$
$$+\frac{\pi\overline{K}_2}{2\,cn\,\alpha\,dn\,\alpha}\left(1+\frac{\alpha}{K}\right)+\frac{\pi\overline{K}_3}{2\,cn\,\beta\,dn\,\beta}\left(1+\frac{\beta}{K}\right) \quad (12)$$

(c) Constants α and β; reduction of equations (9) and (12) to computational form.

It is necessary to reduce equations (9) and (12) to forms suitable for numerical computation. Before this can be done, it is necessary to investigate the nature of α and β. From the computational results in Section (3) and a study of equations (3) and (5), it is evident that

$$-\frac{1}{k}<-\frac{1}{N_1}<t\leq\frac{1}{k}<\left|\frac{p}{qN_2}\right|$$

From the equation

$$sn\,\alpha=-\frac{1}{N_1}<0$$

it follows that the real part of α is negative. Likewise, from

$$sn\,\beta=-\frac{1}{N_2}>0$$

the real part of β is positive. Solving for α and β, we obtain

$$\alpha=sn^{-1}\left(-\frac{1}{N_1}\right)=\int_0^{-\frac{1}{N_1}}\frac{dx}{\left[(1-x^2)(1-k^2x^2)\right]^{\frac{1}{2}}}$$
$$=-\int_0^{+\frac{1}{N_1}>1}\frac{dx}{\left[(1-x^2)(1-k^2x^2)\right]^{\frac{1}{2}}} \quad . \quad . \quad (13)$$
$$=-\int_0^1\frac{dx}{\left[(1-x^2)(1-k^2x^2)\right]^{\frac{1}{2}}}\pm j\int_0^{\frac{\sqrt{(1-N_1^2)}}{k'}}\frac{dx}{\left[(1-x^2)(1-k'^2x^2)\right]^{\frac{1}{2}}}$$
$$=-K+jQ$$

$$\beta=sn^{-1}\left(-\frac{1}{N_2}\right)=\int_0^{-\frac{1}{N_2}>0}\frac{dx}{\left[(1-x^2)(1-k^2x^2)\right]^{\frac{1}{2}}} \quad . \quad . \quad (14)$$
$$=\int_0^1\frac{dx}{\left[(1-x^2)(1-k^2x^2)\right]^{\frac{1}{2}}}+j\int_0^{\frac{\sqrt{(1-N_2^2)}}{k'}>1}\frac{dx}{\left[(1-x^2)(1-k'^2x^2)\right]^{\frac{1}{2}}}$$
$$=K+j\int_0^1\frac{dx}{\left[(1-x^2)(1-k'^2x^2)\right]^{\frac{1}{2}}}-\int_0^{\frac{\sqrt{(d^2-1)}}{k'd}<1}\frac{dx}{\left[(1-x^2)(1-k^2x^2)\right]^{\frac{1}{2}}}$$

where $d=\dfrac{\sqrt{(1-N_2^2)}}{k'}$. Hence

$$\beta=K+jK'-u_0$$

As ξ varies from $-\infty$ to $+\infty$ the closed contour (closed at infinity) of Fig. 3 is obtained. The path of integration in the u-plane, along with the corresponding real points t, y, and ξ, is shown in Fig 3.

In the reduction of equations (9) and (12) we need also the following relations:—

$$sn\,(-K+jQ)=\frac{1}{dn\,(Q,k')}$$
$$cn\,(-K+jQ)=\frac{jk'\,sn\,(Q,k')}{dn\,(Q,k')}$$
$$dn\,(-K+jQ)=\frac{k'\,cn\,(Q,k')}{dn\,(Q,k')}$$
$$Z(jQ)=\frac{j\,sn\,(Q,k')\,dn\,(Q,k')}{cn\,(Q,k')}-jZ(Q,k')-\frac{\pi jQ}{2KK'}$$
$$Z(-K+jQ)=\frac{j\,sn\,(Q,k')\,dn\,(Q,k')}{cn\,(Q,k')}-jZ(Q,k')$$
$$-\frac{\pi jQ}{2KK'}-\frac{jk^2\,sn\,(Q,k')}{cn\,(Q,k')\,dn\,(Q,k')} \quad . \quad (15)$$
$$sn\,(K-u_0+jK)=\frac{1}{k}\frac{dn\,u_0}{cn\,u_0}$$
$$cn\,(K-u_0+jK)=-\frac{jk'}{k\,cn\,u_0}$$
$$dn\,(K-u_0+jK)=-\frac{jk'\,sn\,u}{k\,cn\,u_0}$$

$$Z(K+jK'-u_0)=Z(K+jK')-Z(u_0)+k^2 sn\,(K+jK')\,sn\,u_0\,sn\,(K+jK'-u_0)$$
$$=-\frac{j\pi}{2K}-Z(u_0,k)+\frac{sn\,(u_0,k)}{sn\,(K+u_0)}$$

Applying the above relations to equations (9) and (12), and letting $\overline{K}_n = K_n g$ (where $n = 1, 2, 3$), we obtain

$$\frac{\overline{q}}{g}=2K_1K+\frac{2K_2K\,dn^2\,(Q,k')}{k'^2\,sn\,(Q,k')\,cn\,(Q,k')}\left[\frac{sn\,(Q,k')\,dn\,(Q,k')}{cn\,(Q,k')}-Z(Q,k')-\frac{\pi Q}{2KK'}-\frac{k^2\,sn\,(Q,k')}{cn\,(Q,k')\,dn\,(Q,k')}\right]$$
$$+\frac{2K_3Kk\,cn^2\,(u_0,k)}{k'^2\,sn\,(u_0,k)}\left[Z(u_0,k)-\frac{sn\,(u_0,k)\,dn\,(u_0,k)}{cn\,(u_0,k)}\right]+\frac{\pi K_2\,dn^2\,(Q,k')}{k'^2\,sn\,(Q,k')\,cn\,(Q,k')}\quad . \; . \; . \; . \; . \; . \; . \quad (16)$$

$$\frac{s'-s}{g}=2K_1K'+\frac{2K_2K'\,dn^2\,(Q,k')}{k'^2\,sn\,(Q,k')\,cn\,(Q,k')}\left[\frac{sn\,(Q,k')\,dn\,(Q,k')}{cn\,(Q,k')}-Z(Q,k')-\frac{\pi Q}{2KK'}-\frac{k^2\,sn\,(Q,k')}{cn\,(Q,k')\,dn\,(Q,k')}\right]$$
$$+\frac{2K_3K'k\,cn^2(u_0,k)}{k'^2 sn(u_0,k)}\left[Z(u_0)-\frac{sn\,u_0\,dn\,u_0}{cn\,u_0}-\frac{2K-u_0}{2KK'}\pi\right]\quad . \; . \; . \quad (17)$$

where

$$K_1=\frac{(q-p)(q-b)(q-c)}{\pi q\sqrt{(|B_1A_2|)}},\quad K_2=\frac{M-N}{\pi\sqrt{(|B_1B_2|)}}$$

$$K_3=\frac{Nq-Mp}{\pi q\sqrt{(|B_1B_2|)}}$$

Elimination of the common expressions in equations (16) and (17) gives the relation

$$\frac{\overline{q}}{g}=\frac{K}{K'}\,\frac{s-s'}{g}+\frac{\pi(2K-u_0)kK_3\,cn^2\,(u_0,k)}{K'k'^2\,sn\,(u_0,k)}+\frac{\pi K_2\,dn^2\,(Q,k')}{k'^2\,sn\,(Q,k')\,cn\,(Q,k')}\quad . \; . \quad (18)$$

(d) Transformation from the ξ-plane to the W-plane.

The potentials of the armature and field being respectively 0 and $\frac{1}{2}$, the Schwarzian transformation between the ξ- and W-planes is

$$W\equiv\Phi+j\Psi=B\int\frac{d\xi}{\xi}=B\,(\log|\xi|+j\theta)\quad . \quad (19)$$

To determine B, we have

$$\Phi_{\text{field}}-\Phi_{\text{armature}}=\frac{1}{2}=B\int_{\pi}^{0}\frac{d\xi}{\xi}=-Bj\pi$$

whence $B=\dfrac{j}{2\pi}$

By evaluating the integral in equation (19) between the limits $\xi=-1$ and $\xi=a$, and equating reals and imaginaries, the value of the permeance in the region of interest is found to be

$$\Psi_1=\frac{1}{2\pi}\log a$$

in c.g.s. units.

REPORT OF THE COUNCIL FOR THE YEAR 1937-1938, PRESENTED AT THE ANNUAL GENERAL MEETING OF THE 12TH MAY, 1938

CONTENTS

REPORT

The Council have pleasure in presenting to the members, at the Sixty-Sixth Annual General Meeting, their report of the work done during the Session 1937–38. In submitting this account of the activities of The Institution during the period under review, 1st April, 1937, to 31st March, 1938, the Council are mindful of the generous services rendered by many members in connection with the work upon which the Council and its numerous Committees, including those of the Local Centres and Sub-Centres and the Committees overseas, have been engaged. To these members cordial thanks are expressed for their valuable co-operation in helping to further the interests of The Institution.

(1) MEMBERSHIP OF THE INSTITUTION

The changes in the membership since the 1st April, 1937, are shown in a Table included in Appendix A.

The following Table shows the net growth of membership for the last 10 years:—

Year	*Membership*	*Increase*
1929	13 561	518
1930	14 200	639
1931	14 670	470
1932	14 884	214
1933	15 149	265
1934	15 619	470
1935	16 150	531
1936	16 788	638
1937	17 399	611
1938	18 252	853

(2) HONORARY MEMBER

The Council have pleasure in recording that, as announced at the Ordinary Meeting on the 20th January, 1938, they elected Mr. Frank Gill, O.B.E. (Past-President), to be an Honorary Member of The Institution.

(3) FARADAY MEDAL

The sixteenth award of the Faraday Medal was made by the Council to Sir John F. C. Snell, G.B.E. (Honorary Member; Past-President).

(4) HONOURS AND DISTINCTIONS CONFERRED ON MEMBERS

K.B.E.

Couzens, Henry Herbert (Associate Member).

O.B.E.

Anson, Bernard Oglie (Member).

Crawley, Lt.-Col. Chetwode George G. (Member).

M.B.E.
Sizer, Nelson, M.C. (Associate Member).

I.S.O.
Kennedy, Peter (Member).

Kernot Memorial Medal (University of Melbourne).
Wheadon, Frederick William H. (Member).

(5) KELVIN MEDAL

It is with much pleasure that the Council here record that the Kelvin Medal Award Committee, which consists of the Presidents of eight leading Engineering Institutions, decided in February last to award the Kelvin Medal for 1938 to Sir Joseph J. Thomson, O.M., D.Sc., F.R.S. (Honorary Member and Faraday Medallist, I.E.E.) in recognition of the eminent services rendered by him to engineering science in those branches of engineering work or investigation with which Lord Kelvin was especially identified.

Previous recipients of the Medal, which is awarded triennially, were as follows:—

1920 The late Dr. W. C. Unwin, F.R.S. (Great Britain)
1923 The late Dr. Elihu Thomson (United States of America)
1926 The late the Hon. Sir Charles A. Parsons, O.M., K.C.B., F.R.S. (Great Britain)
1929 Professor André Blondel (France)
1932 The late Marchese Marconi, G.C.V.O., D.Sc. (Italy)
1935 Sir Ambrose Fleming, M.A., D.Sc., F.R.S. (Great Britain)

(6) DEATHS

The Council regret to have to record the death of the following 105 members of The Institution during the year:—

Honorary Member

Marconi, His Excellency the Marchese, G.C.V.O., D.Sc.

Members

Acland, R. L.
Arnall, A. T., B.Sc.
Bishop, H. C.
Clothier, H. W.
Conner, J.
Couves, H. A.
Crawley, C. W. S.
Cross, W.
Dania, G.
Daubeny, E. C.
Davy, A.
Down, F. J.
Evans, L. M.
Gamlen, R. L., O.B.E.
Gavey, A.
Gerrard, F. B.
Guy-Pell, W.
Holden, Sir H. C. L., Brig.-General, K.C.B., F.R.S., R.A.
Hughes, R. J.
Jackson, A. E.
Jackson, F. H.
Jones, A. W.
McLachlan, J.
Maclean, Prof. M., D.Sc., LL.D., F.R.S.E.
Martin-Cooper, B. A.
Mather, Prof. T., F.R.S.
Neele, C. W.
Roberts, J.
Robertson, R. K.
Roux, G. P.
Shrimpton, E. A.
Stewart, J. E.
Stothert, J. K.
Tapper, J. E.
Taylor, H. W.
Thompson, J. H.
Thomson, J. A. V.
Wigg, C. B.
Wild, J. H.

Associate Members

Anderson, E. A.
Arrowsmith, S. J.
Barnard, F. G.
Barnard, J.
Baxter, J. H.
Bland, A. V.
Bolton, E.
Burri, F.
Carlmark, J. D.
Christie, J. C.
Davies, E. W.
Durant, J. H.
Faber, S. A.
Fethney, W. H.
Field, J. H., C.S.I., M.A., B.Sc.
Giles, H. W.
Goodman, J.
Hammond, E. J.
Hawken, W. T.
Heron, C. R., M.B.E.
Hills, R.
Jones, E. W.
Kennard, A. E.
Lewis, E. A., Major, D.S.O.
Lindley, G., M.Eng.
Lovell, W. H., M.C.
McCandless, J.
Mallalieu, J. E.
Mentasti, R. G. B.
Newton, C. E.
O'Reilly, E. L., B.E., B.Sc.
Rebeiro, A. J. L.
Reeves, A. R.
Robertson, H. F.
Russell, C. J.
Stirrup, J.
Taggart, J. E.
Thomas, J.
Tilney, M. J. E.
Wallace, M. G., B.Sc. (Eng.).
Waring, H.
Wilton, N. V. S.

Companion

Maling, F. T.

Associates

Cockerill, T.
Grigg, Major R.
Hughes, A.
Hurst, W. G.
Innes, A.
Leach, G. C.
Leeder, G. W. E. B.
Miles, H.
Pell, W. M. D.
Shiels, J. H.
Taylor, J. R.

Graduates

Hill, C. A. R.
Ingall, H. K., B.A.
McLaughlin, D. H. C.
Mehta, H. R.
Riley, S.
Sekhar, M. S. C.
Skinner, J. C., B.A.

Students

Gray, G. A.
King, E. R.
Pink, F.
Thornton, R. M.

(7) EXAMINATIONS

Graduateship Examinations were held for a total of 628 candidates in May and November, 1937, in London, Belfast, Birmingham, Cardiff, Dublin, Glasgow, Loughborough, Manchester, and Newcastle-on-Tyne, and also, in November only, in Argentina, Australia, Ceylon, Egypt, Federated Malay States, India, Malta, New Zealand, and South Africa.

Examinations in English only were also held in May and November, 1937, at various centres in Great Britain for 265 holders of National Certificates in Electrical Engineering.

In addition, 13 candidates over 30 years of age were permitted to fulfil the educational requirements for Associate Membership by the submission of satisfactory papers or theses in lieu of the Examination.

The Page Prize was awarded to Mr. J. O. Knowles, M.A., for his thesis entitled "Rupturing Capacity in Motor Cir-

cuits." This prize is offered annually for the best paper or thesis submitted in lieu of the Examination, provided that one has been received of sufficient merit to justify an award.

The Council have approved draft Regulations prepared by the Engineering Joint Council to inaugurate a scheme for a Common Preliminary Examination for all the co-operating Institutions.

This scheme provides for the setting up of an Engineering Joint Examination Board on which The Institution will be represented, and although candidates for I.E.E. Studentship are not at present required to pass an examination, the facilities of the scheme will be available for the use of The Institution should the Council so desire.

(8) NATIONAL CERTIFICATES AND DIPLOMAS IN ELECTRICAL ENGINEERING

England and Wales.—In 1937 the Joint Committee, representing the Board of Education and The Institution, were associated with the final examinations of 211 courses at colleges and schools in England and Wales, approved in connection with the above certificates and diplomas.

The final examinations were held during the summer and the number of awards was as follows:—

Ordinary Certificates	816
Higher Certificates	407
Higher Certificates endorsed	62
Ordinary Diplomas	27
Higher Diplomas	16
Total	1 328

Scotland.—In conjunction with the Scottish Education Department, The Institution was associated with 16 courses in Scotland during the year under review.

The final examinations were held during the summer, and the number of awards was as follows:—

Ordinary Certificates	38
Higher Certificates	18
Higher Diplomas	7
Total	63

(9) SCHOLARSHIPS

The following Scholarships have been awarded by the Council during the Session:—

Duddell Scholarship
(Annual Value £150; tenable for 3 years.)
R. S. Peacock (King's School, Ely).

Silvanus Thompson Scholarship
(Annual Value £100, plus tuition fees; tenable for 2 years.)
J. R. Catlin (Igranic Co., Ltd.).

William Beedie Esson Scholarship
(Annual Value £120; tenable for 2 years, renewable in approved cases for a third year.)
R. P. Kinsey (Evershed & Vignoles, Ltd.).

Swan Memorial Scholarship
(Value £120; tenable for 1 year.)
B. C. Robinson, Ph.D. (King's College, Newcastle-on-Tyne).

David Hughes Scholarship
(Value £100; tenable for 1 year.)
L. Lieberman (Queen Mary College, London).

Salomons Scholarship
(Value £100; tenable for 1 year.)
S. G. Bittles (College of Technology, Belfast).

Paul Scholarship
(Annual Value £50; tenable for 2 years.)
F. L. Johnson (Holloway School, London).

Thorrowgood Scholarships
(Annual Value £12 10s. each; tenable for 2 years.)
J. S. Davis (London, Midland and Scottish Railway Co.).
W. P. Hill (London Passenger Transport Board).

There was no award of the Ferranti Scholarship, the value of which is £250 per annum for two years.

War Thanksgiving Education and Research Fund (*No.* 1)
Grant of £50 to:—
J. E. Parton, B.Sc. (Birmingham University).

All the Scholarships mentioned above, and the grant, may be awarded annually with the exception of the Paul and William Beedie Esson Scholarships, which are awarded in alternate years only. When an award of the latter scholarship is renewed for a third year, however, the next award is deferred for a year.

In addition to the above awards special grants of £50 each have been made to:—

G. King (City and Guilds College, London).
F. H. Last (Queen Mary College, London).

(10) COOPERS HILL WAR MEMORIAL PRIZE

The award of the Coopers Hill War Memorial Prize, which consists of a bronze medal, a parchment certificate, and a money prize of £20, fell this year to The Institution, and the Council selected for the award Dr. T. E. Allibone for his paper on "The Mechanism of the Long Spark." Seven papers were submitted for consideration.

Only Corporate Members of The Institution under 35 years of age are eligible to compete. The Prize consists of two awards, one of which is made annually by The Institution of Civil Engineers, and the other triennially in turn by The Institution of Electrical Engineers, the School of Military Engineering, Chatham, and the School of Forestry, Oxford.

(11) INSTITUTION BUILDING

As in past years, the use of The Institution's premises has been granted without charge to a number of kindred societies in connection with their meetings, and 188 such meetings have been held during the past year.

(12) MEMBERS OF LONG STANDING

In the last Annual Report it was announced that the Council had decided that as soon as a member of any

class has attained his 50th year of membership of The Institution he might, if he so desired, cease to pay any further annual subscriptions. This rule has since been revised, and now provides that as soon as a member of any class has completed 50 years of membership, he will automatically cease to be asked to pay any further subscriptions.

(13) MEETINGS

During the past 12 months, 557 meetings were held in London and at the Local Centres by the members, the Council, and the various Committees. A detailed statement is given in Appendix B.

The average attendance at the 17 Ordinary Meetings held in London was 255, compared with 262 for last Session.

The programme this Session has included Joint Meetings with the British Section of the Société des Ingénieurs Civils de France and with the Plastics Group of The Society of Chemical Industry, at which papers of common interest have been read and discussed. A Joint Meeting will also be held in April, 1938, with The Institution of Chemical Engineers. In addition, an invitation was gladly accepted to participate in a Joint Meeting with The Institution of Civil Engineers, in March, 1938, at which papers on the Fulham Power Station were read and discussed, and The Institution co-operated with some 16 other bodies in the holding, also in March, 1938, of a "Joint Meeting of Kindred Societies," arranged by The Institution of Automobile Engineers, for the discussion of papers on the subject of "Essential Road Conditions covering the Safety of Modern Traffic."

(14) PREMIUMS

The Premiums awarded by the Council for papers read at meetings or accepted for the *Journal* will be announced* about the time of the Annual General Meeting.

(15) LOCAL CENTRES AND SUB-CENTRES

The activities of the Local Centres and Sub-Centres, full details of which are contained in the Annual Reports presented to the local members, continue to be well supported and the Council wish to record their appreciation of the valuable work done by these branches of The Institution. By their constant efforts in furthering local activities, the officers and committees of the Centres and Sub-Centres contribute materially to the advancement of The Institution, and the presence of the Centre Chairmen at meetings in London of the Council and its Committees greatly assists in maintaining the contact with headquarters which is so essential.

The President attended functions at the Centres at Birmingham, Cardiff, Glasgow, Leeds, Liverpool, Manchester, and Newcastle-on-Tyne, as well as at the Hampshire, Sheffield, and Tees-Side Sub-Centres; and he hopes to be present at functions in Belfast and Dublin in May. He was represented at the Annual Dinner of the East Midland Sub-Centre by Dr. A. P. M. Fleming, C.B.E., M.Sc., Vice-President, and the Annual Dinner of the West Wales (Swansea) Sub-Centre was attended by Mr. Johnstone Wright (Vice-President).

In addition to the above, the four Vice-Presidents, Sir Noel Ashbridge, Mr. J. R. Beard, Dr. A. P. M. Fleming, and Mr. Johnstone Wright, have among them, at the invitation of the Local Committees and with the warm approval of the Council, attended various meetings of the Local Centres and Sub-Centres during the Session.

The Council have during the Session approved the formation of a Sub-Centre in Devon and Cornwall, and three meetings have so far been held. At the first of these, the Interim Chairman gave an Address, and papers were read and discussed at the remaining two.

Members are reminded that local technical libraries for their use have been established at Birmingham, Dublin, Liverpool, Loughborough, Manchester, Middlesbrough, Newcastle-on-Tyne, Portsmouth, and Southampton. Full details of the arrangements for borrowing or referring to the books at these libraries can be obtained on application to the Local Honorary Secretaries.

The Annual Meeting of the Honorary Secretaries of Local Centres and Sub-Centres was held in London on the 10th February, 1938, when matters of common interest in regard to local organization and administration were discussed.

(16) METER AND INSTRUMENT SECTION

The membership of the Meter and Instrument Section is now 711. Nine meetings of the Section have been held during the past year, the average attendance being 113, which compares with 105 during the preceding 12 months. The meetings included one which was devoted to an Informal Discussion. Demonstrations of apparatus accompanied papers whenever practicable, and added greatly to the interest and success of the meetings.

The Committee wish to remind the members that short demonstrations will be welcomed of apparatus and processes which come within the scope of the Section. These need not necessarily relate to the subject matter of the paper being read on the same evening.

The Summer Visit for 1937 was held in the North London and St. Albans districts on Saturday, 8th May, 1937, and about 120 members and ladies took part. In the morning visits were paid to the Meter Department of the North Metropolitan Electric Power Supply Co. at Friern Barnet, the Brimsdown Power Station, and the Works of the British Sangamo Co., Ltd., at Enfield. After lunch as the guests of the last-named Company, the party proceeded to St. Albans where the Abbey and the Roman excavations were seen, and tea was provided by the North Metropolitan Electric Power Supply Co. The Section Committee wish to record their thanks for the hospitality accorded by this Company and by the British Sangamo Co., Ltd.

The Section held its Annual Dinner on the 19th November, 1937, the attendance being 278.

(17) TRANSMISSION SECTION

The Transmission Section now has a membership of 1 680. Seven meetings have been held during the past year, the average attendance being 117, compared with 95 during the preceding 12 months. The papers have been of a high standard and have been followed by excellent discussions.

The Summer Visit of the Section was held in Kent on Saturday, 1st May, 1937, when nearly 150 members and

* See vol. 82, page 698.

ladies took part in an inspection of the Works and Research Laboratories of Messrs. W. T. Henley's Telegraph Works Co., Ltd., at Gravesend. Lunch and tea were provided by the company, to whom the thanks of The Institution are due for the excellent arrangements made and the hospitality accorded.

Following the successful week-end visit to Paris last year, a similar visit was paid to Holland at the invitation of the Vereeniging van Directeuren van Electriciteitsbedrijven in Nederland, from the 18th to the 21st June, 1937, 51 members taking part. The programme included visits to the Nijmegen power station and the 50-kV outdoor station of the Provincial Supply Undertaking of the Gelderland, the laboratories of the KEMA (Testing Laboratories for Electrical Material, Ltd.), the Agricultural High School of Wageningen, where test fields for plant culture by electrical means were inspected, the 50-kV totally enclosed outdoor station at Veenendaal of the Provincial Supply Undertaking of Utrecht, and also one of that organization's 10-kV substations. In addition there were the motor-coach tours through the Provinces of Gelderland and Utrecht for the purpose of viewing the rural electrification systems there. The Council desire to express their thanks for the hospitable welcome extended to the party and for the excellent arrangements made by the Dutch engineers, which contributed so largely to the success of the visit.

Continuing the series of visits to works inaugurated two years ago, an interesting visit was paid on Wednesday, 8th December, 1937, to the works of Steatite and Porcelain Products, Ltd., at Stourport. Approximately 50 members took part. The Section Committee have conveyed their cordial thanks to the company for the excellent arrangements made to receive the party.

The Annual Conversazione and Dance of the Section, which was held on Wednesday, 3rd November, 1937, once again proved very successful, being attended by 242 members and guests.

(18) WIRELESS SECTION

The membership of the Wireless Section is now 967. Eight meetings have been held during the past year, at which 6 papers were read, and a lecture was delivered by Dr. B. van der Pol on "Discontinuous Phenomena in Radio Communication." In addition, 14 papers have been published or accepted for publication in the *Journal*. The average attendance at the meetings was 131, compared with 151 for last Session.

The Section Informal Meetings which were introduced in January, 1935, have continued to be well supported. Three meetings have been held, and the average attendance was 225, which compares with 137 during the previous Session.

The Summer Visit for 1937 took place on Saturday, 29th May, 1937, when a party consisting of 94 members visited the B.B.C. London Television Station at Alexandra Palace. Thanks have been accorded to the British Broadcasting Corporation for the arrangements made to receive the party.

(19) INFORMAL MEETINGS

Eleven meetings have been held during the year, the average attendance being 65, as against 72 last year.

The Informal Meetings Committee again cordially invite members to write to the Secretary indicating subjects which they wish to suggest for discussion. Offers from members to open discussions will also be welcomed and carefully considered by the Committee.

The Council wish to remind the younger members, and particularly those who have not yet attended any of the meetings, that these are arranged primarily for them, with the object of their gaining experience in public speaking and thereby acquiring confidence to take part in the discussions on papers at the Ordinary Meetings.

The proceedings of the Informal Meetings are not reported by the Press, and only a précis of the discussions (prepared by a member of the Committee) is sent to the technical journals for publication.

(20) STUDENTS' SECTIONS

The nine Students' Sections at London, Birmingham, Bristol, Glasgow, Leeds, Liverpool, Manchester, Newcastle-on-Tyne, and Sheffield, have carried out during the Session a full programme of meetings, visits to works, and social functions, details of which have been given from time to time in the *Students' Quarterly Journal*.

The membership of the nine Sections is in the aggregate 4 164, which includes 1 965 Graduates up to the age of 28, who are entitled under the Bye-laws to the same privileges as Students.

The "Students' Lectures" were again delivered this Session by Mr. J. W. Thomas, LL.B., B.Sc.Tech., and Mr. J. N. Waite, who on this occasion visited the places indicated:—

Lecturer.	*Subject.*	*Place.*
Mr. J. N. Waite	"Engineering and Administration."	London Birmingham Bristol Liverpool Manchester
Mr. J. W. Thomas, LL.B., B.Sc.Tech.	"Law as it affects the Engineer."	Edinburgh Glasgow Leeds Newcastle-on-Tyne Sheffield

The total attendances at the 10 lectures were approximately 490, compared with 480 for the 10 lectures given last Session. Arrangements have been made for Mr. J. W. Beauchamp and Mr. Arthur Duxbury to be the lecturers next Session. Mr. Beauchamp will deal with the subject of "The Electrical Industry as an Economic and Social Force," and Mr. Duxbury will give a lecture on "Public Speaking," similar to the very successful lecture delivered by him this Session at a meeting of the London Students' Section. The Council hope that the lectures next Session will receive greater support, as it is felt that the present attendance figures could be considerably improved upon, especially taking into account the total membership of the Sections.

The Seventh Annual Meeting of the Honorary Secretaries of the Sections was held in London on the 11th February, 1938, when a useful discussion took place on points of common interest.

The *Students' Quarterly Journal* continues to assist the

younger members of the profession, by whom it is held in high regard. Almost all those who remember its inauguration have now transferred to higher grades of membership, but the tradition built up by the early enthusiasm, supplemented by occasional editorial comment, is resulting in a steady flow of material which enables the various issues to present a suitably varied make-up.

Senior members of The Institution are reminded that copies of the publication can be obtained by them on payment of an annual subscription of 6s. The charge to the general public is 10s. per annum.

The London Students' Section this year failed to retain the "Young" Trophy in the Sports Contest between that Section and the Students and Graduates of The Institutions of Civil and Mechanical Engineers. The Section had held the Trophy for the three previous years, that is since the inception of the Contest. The Contest consisted of cricket, tennis, and shooting matches, a full account of which was given in the September number of the *Students' Journal*.

(21) ACTIVITIES OF OVERSEAS MEMBERS

The Overseas Activities Committee of the Council are very gratified at the continued progress of The Institution overseas. Details have been received of meetings at which papers have been read and discussed, and other functions which have been arranged by the Argentine and China Local Centres and by the Local Committees in New South Wales, Queensland, South Australia, Victoria, Western Australia, New Zealand, Ceylon, Bombay, Calcutta, Lahore, and Madras.

In some instances papers already read in London have been read and discussed, and papers have also been written and presented by local members.

The schemes of co-operation with other Institutions initiated in the Argentine and China continue to operate very satisfactorily.

The sixth Annual Conversazione and Reunion of members from overseas, and their ladies, was held in the Institution building on Wednesday, 7th July, 1937. The total attendance was about 130, and the arrangements were similar to those made for the four previous functions. An account of the proceedings was published in the *Journal* for September, 1937 (vol. 81, page 489).

(22) CO-OPERATION BETWEEN ENGINEERING INSTITUTIONS

The Council have recently discussed, on the suggestion of the President, the question of securing closer co-ordination between the large Engineering Institutions, and arising from this it has become evident that the other Institutions concerned fully agree that endeavours should be made to find the maximum amount of co-operation possible, not only as regards activities in London, but between the Local Centres and similar branches of the various Institutions. The matter will therefore receive the attention of the Council with a view to establishing close relations and to helping to knit the Institutions together.

With reference to overseas members of the various Institutions the Engineering Joint Council have recently, at the request of this Institution, considered what steps can be taken further to bring these members together, the suggestion being that the schemes of co-operation already in existence in China and the Argentine might be the basis of similar co-operation elsewhere overseas. A report of a special Committee set up by the Joint Council to discuss this matter is now available giving details of a suggested scheme for carrying out the object in view. The report provides for the appointment in London of a standing Joint Committee, whose duty it would be to put the scheme into operation and further its progress in the future in every way possible. This report is under consideration by the Councils of this and other Institutions.

(23) CHINESE ELECTRICAL ENGINEERING APPRENTICES AND STUDENTS

The Council have decided that facilities to attend Institution meetings and to use the Reference Library should, as a gesture of goodwill, be offered to Chinese electrical engineering apprentices and students who, under arrangements made by the Federation of British Industries, have been given opportunities for engineering experience in Great Britain with the object of improving and fostering relations with China. The Federation have so far supplied the names of some 20 young men who come within the scope of the scheme. Such of them as are engaged in the provinces have, with the ready co-operation of the Local Centres and Sub-Centres concerned, been granted similar privileges as regards attendance at local meetings and use of any library facilities that may be available.

(24) REVIEWS OF PROGRESS

Continuing the series of reviews of progress in electrical engineering, which have appeared in the *Journal* each year since 1926, reviews on the following subjects will be published during 1938:—

Radiological and Electromedical Apparatus
Electricity Supply Tariffs.

Arrangements have been made for reviews on the following subjects in 1939:—

Broadcasting and Television.
Power Stations and their Equipment.
Radio-Telegraphy and Radio-Telephony.
Telegraphy and Telephony.

(25) FARADAY LECTURE

The Faraday Lecture this Session has been delivered by Dr. A. P. M. Fleming, C.B.E., M.Sc., who chose as his subject "The Evolution of Electrical Power." It has been given at Birmingham, Dublin, Edinburgh, Leeds, Liverpool, Manchester, Newcastle-on-Tyne, and Newport, and will also be given in Dundee and London before the Session closes.

The 8 Lectures so far delivered this session have been attended by audiences totalling approximately 5 980, of whom over 4 930 were non-members.

(26) SUMMER MEETING

The Council have accepted a cordial invitation from the Chairman and Committee of the South Midland Centre for a Summer Meeting to be held in the area of that Centre from the 4th to the 8th July, 1938.

(27) ANNUAL CONVERSAZIONE

The Annual Conversazione was held on the 1st July, 1937, at the Natural History Museum, London. The total attendance of members and guests was 1 942.

(28) ANNUAL DINNER

The Annual Dinner was held at Grosvenor House, Park Lane, London, on the 10th February, 1938, when 1 111 members and guests were present. An account will be published in the *Journal*.*

(29) ANNIVERSARY CELEBRATIONS AND CONFERENCES

During the year under review, The Institution has been represented at the following Anniversary Celebrations and Conferences, etc.:—

Name of Body.	*Nature and Date of Function.*	*Name of I.E.E. Representative.*
Association of Teachers in Technical Institutions	Annual Conference, Coventry (15–18 May, 1937)	W. J. Marston
Associazione Elettrotecnica Italiana	Annual Reunion, Bari (21–28 September, 1937)	L. Emanueli (Local Honorary Secretary for Italy)
Engineering Institute of Canada	Semi-centennial Celebrations, Montreal (15–18 June, 1937)	Johnstone Wright (Vice-President)
Institution of Engineers, Australia	Annual Conference, Sydney (week commencing 28 March, 1938)	V. J. F. Brain (Local Honorary Secretary for New South Wales)
National Smoke Abatement Society	Ninth Annual Conference, Leeds (30 September–2 October, 1937)	W. B. Woodhouse S. R. Siviour
Royal Sanitary Institute	Annual Health Congress, Birmingham (12–17 July, 1937)	F. Forrest E. A. Reynolds

In addition, by the direction of the Council, a Congratulatory Address was presented by The Institution's representative at the Semi-centennial Celebrations of The Engineering Institute of Canada (see above) and a cablegram of greeting was sent to The Institution of Engineers, Australia, at its Annual Conference in Sydney. A Congratulatory Address was also sent to The Institute of Electrical Engineers of Japan on the occasion of its Golden Jubilee Celebrations held on the 1st April, 1938.

(30) INTERNATIONAL CONFERENCE ON LARGE H.T. SYSTEMS

The ninth Session of the above Conference took place in Paris from the 24th June to the 2nd July, 1937. The number of registered members of the Session was 871, representing 41 countries, Great Britain having 88 such members. The British National Committee of the Conference presented 10 papers for reading at the Session.

The Council have considered the question of the continuance of the British National Committee as a Committee of The Institution and have decided that the time has arrived for the Committee to be separated from, and to act independently of, The Institution. The Council have therefore decided, as from 10th March, 1938, to dissolve the existing Committee, and a new Committee will take its place. The Institution will have two representatives on the new Committee, and arrangements have been made with the British Electrical and Allied Industries Research Association to act as the new Secretariat.

(31) LIBRARY

During the year 393 books and pamphlets were presented to the Reference Library by members and others and 109 volumes were purchased. The total number of readers for the year was 7 226, of whom 889 were non-members, as against 6 781 and 602 respectively in 1936–37.

Sixty-four new volumes were added to the Lending Library and 2 905 books were issued to 1 231 borrowers, the corresponding numbers for the previous year being 2 963 and 1 224 respectively.

(32) GIFTS TO THE INSTITUTION

The Council express their cordial thanks to the donors of the following gifts to The Institution:—

Donors.	*Gifts.*
Mr. C. W. Cassé	Two high-candle-power "Sunbeam" carbon-filament lamps from the Taj Mahal, Agra, installed in 1904.
Sir Alexander Gibb	An etching of The Institution of Civil Engineers' building.
Mr. J. S. Highfield and Mr. W. E. Highfield	Mounted specimen of 150-kV cable (Moutiers-Lyons), Thury system (1906–1936).
Sir George Lee, O.B.E., M.C.	A speech-level indicator for use in the Lecture Theatre.
Mr. F. C. Porte	Page electric motor (1851).
Mr. H. T. Young	Six engravings of old London, and an album containing a collection of old prints of the Savoy and district.

(33) OIL PAINTINGS

The oil painting of Mr. Sydney Evershed which was referred to in the last Annual Report was formally presented to The Institution on Thursday, 16th December, 1937, by Lieut.-Col. W. A. Vignoles, D.S.O., on behalf of the many business associates and admirers of Mr. Evershed who subscribed towards it. The painting is by Mr. George Harcourt, R.A.

(34) PARSONS ANNUAL MEMORIAL LECTURE

The Second Parsons Annual Memorial Lecture, which The Institution, as indicated in the last Annual Report, was invited by the Royal Society to sponsor, was delivered at the Ordinary Meeting held on the 25th November, 1937. Dr. Gerald Stoney, F.R.S., Member, was the

* See page 207.

lecturer, his subject being "Scientific Activities of the late Hon. Sir Charles A. Parsons, O.M., K.C.B., F.R.S." At the conclusion of the Lecture a commemorative bronze medal provided from the Memorial Fund was presented to Dr. Stoney by the President.

(35) ALEXANDER GRAHAM BELL

The memorial plaque to Alexander Graham Bell, mention of which was made in the last Report, was duly unveiled at 16, South Charlotte Street, Edinburgh, by the President before a representative gathering on Wednesday, 24th November, 1937. The plaque indicates that Alexander Graham Bell, the inventor of the telephone, was born at that address on the 3rd March, 1847. A brief account of the proceedings has been published in the *Journal*.*

(36) HISTORY OF THE INSTITUTION

The preparation of the "History of the Institution" by Mr. Rollo Appleyard is well in hand. It would be of considerable assistance to the author if members would send to him at The Institution any reminiscences or information of historical interest which they think may be of use.

(37) VISITING MEMBERS

The list of kindred Institutions overseas with whom The Institution has come to a reciprocal arrangement for the extension of privileges to visiting members has been extended this Session by the inclusion of the Verband Deutscher Elektrotechniker of Berlin. The complete list of Institutions with which such arrangements have been made is now as follows:—

The American Institute of Electrical Engineers, New York;
The Institute of Electrical Engineers of Japan, Tokio;
The Norsk Elektroteknisk Forening, Oslo;
The Société Française des Électriciens, Paris;
The South African Institute of Electrical Engineers, Johannesburg; and
The Verband Deutscher Elektrotechniker, Berlin.

(38) INTERNATIONAL ENGINEERING CONGRESS GLASGOW, 1938

As announced in the last Annual Report The Institution, in collaboration with other Engineering Institutions, is according its support to the International Engineering Congress to be held in Glasgow from the 21st to the 24th June, 1938, concurrently with the Empire Exhibition. Full particulars of the programme of Technical Sessions, visits to works, excursions and social events arranged by the organizing committee were issued to members with the March number (No. 495) of the *Journal*.

(39) ELECTRICAL EQUIPMENT OF OPERATING THEATRES AND ADJACENT ROOMS

As a result of the discussion on the papers by Prof. W. M. Thornton, O.B.E., D.Sc., D.Eng., entitled "The Electrical Ignition of Mixtures of Ether Vapour, Air, and Oxygen" and Dr. E. H. Rayner, M.A., Sc.D., entitled "The Risk of Explosion due to Electrification in Operating Theatres of Hospitals," which took place at the Ordinary Meeting on the 24th February, 1938, the Council have decided to set up a Committee representative of the various interests concerned, to consider:—

(i) the electrical conditions and design of equipment necessary for the elimination of the risk of explosions in operating theatres and adjacent rooms,
(ii) the desirability of a Code of Safety Rules, and
(iii) the arrangements which are appropriate for ensuring that safe equipment is installed and safe conditions maintained.

This Committee has been given power to co-opt additional experts for the consideration of special branches of its study and has been instructed to co-operate with the Medical Research Council, the Wiring Regulations Committee, and The British Standards Institution, on matters which fall naturally within the sphere of these bodies. Other interested authorities and medical bodies are being consulted in connection with the work of the Committee.

(40) REGULATIONS FOR THE ELECTRICAL EQUIPMENT OF BUILDINGS

The Wiring Regulations Committee have made considerable progress in the preparation of the Eleventh Edition, and the majority of the Sub-Committees have submitted their final reports in connection with the revision of the Regulations.

(41) REGULATIONS FOR THE ELECTRICAL EQUIPMENT OF SHIPS

The revision of the Second Edition is well in hand, and several of the Sub-Committees appointed to assist in the revision have submitted draft revised Sections for consideration by the Ship Electrical Equipment Committee.

A special Panel has been appointed to formulate draft Regulations for the prevention of radio interference caused by ships' electrical machinery.

(42) EARTHING TO WATER MAINS

The Council, acting on a recommendation of the I.E.E. Joint Committee on Earthing to Water Mains, have decided to contribute a sum of £50 a year for a period not exceeding 3 years towards the cost of research to be undertaken by a Joint Committee (on which the I.E.E. is represented) of The Institution of Civil Engineers and the Electrical Research Association in connection with problems which arise in regard to earthing to water pipes and mains.

The Council have also approved, subject to comments from interested Associations being considered, draft regulations* in connection with earthing to water pipes and mains, drawn up by the Research Sub-Committee of The Institution of Civil Engineers as a basis for agreement between the electrical industry and water authorities.

* See vol. 82, page 223.

* See page 434.

(43) ENGINEERING PUBLIC RELATIONS COMMITTEE

As a result of a Joint Meeting of leading Institutions held at The Institution of Civil Engineers in December, 1936, a Committee (consisting of representatives of some 14 of the principal Engineering Institutions) was formed last year for the purpose of disseminating knowledge for the general advancement of engineering science by presenting to the public in suitable form information concerning the science and practice of engineering and its services to the public. The Council decided to give their support to this Committee, at any rate for the first year, and they accordingly appointed a representative to serve thereon. A preliminary programme of work drawn up by the Committee has now been put into operation, and includes the provision of lectures for schools, public lectures for large audiences, Christmas Lectures to young people, the issue to schools, etc., of an illustrated pamphlet on engineering, closer co-operation with the Press, co-operation with the B.B.C., etc. As regards the Christmas Lectures, these were commenced this year, when two lectures under the title of "Senior-School Christmas Lectures in Engineering" were given, by permission of the Council, in the I.E.E. Lecture Theatre on the 7th and 10th January, 1938, by Prof. C. E. Inglis, O.B.E., F.R.S., who took as his subject "Building Big Bridges." The attendance was approximately 450 at each lecture.

It is appropriate to record here that the Committee was instrumental in obtaining the agreement of the Chief Passport Officer that Chartered Engineers who are British subjects resident in the United Kingdom shall in future be recognized as persons authorized to sign the declarations of applicants for British passports. This was referred to in the November (1937) number of the *Journal* (vol. 81, page 693). Any Member or Associate Member of this Institution signing such declarations should insert after his name the designation "Chartered Electrical Engineer."

(44) ENGINEERS' GERMAN CIRCLE

The Council have agreed to support the Engineers' German Circle which has already, since its inauguration in 1931, had the support of The Institution of Mechanical Engineers, and with this object they have nominated a member of The Institution, who is also a member of the Circle, to maintain the necessary contact. Active support will commence next Session when The Institution will include in its announcements to members particulars of the meetings of the Circle, so that those interested may attend its lectures. These are in German and are by eminent German-speaking engineers. It is understood that on each occasion they are followed by a short discussion in German. Those present are thus enabled to further their knowledge of technical German. Members of the Circle pay a subscription of 7s. 6d. per annum.

(45) "SCIENCE ABSTRACTS"

The Physics volume of *Science Abstracts* for 1937 contains 5 494 abstracts, compared with 5 716 in 1936. The Electrical Engineering volume contains 3 252 abstracts, compared with 3 525.

A feature of the Annual Index to Section "A" (Physics) which has proved of considerable value since its introduction in 1934, is the inclusion of a "Supplementary Index of Apparatus and Instruments," in which the papers are classified under the names of the instruments and are arranged in alphabetical order.

Science Abstracts, which appears monthly in two sections, namely Section "A" (Physics) and Section "B" (Electrical Engineering), consists of full abstracts from the leading scientific and technical journals and the proceedings of learned societies of the whole world, and presents in a form convenient for immediate reference a complete and concise record of the progress of physical science and electrical engineering. 1 424 members of The Institution subscribe to *Science Abstracts*, 831 subscribing to both Sections and 587 to Section "B," but the Council hope that in view of its exceptional value more members will become subscribers to the publication. It may be obtained, if ordered in advance, by Students of The Institution, as well as by Graduates up to the age of 28, at the special rate of 7s. 6d. per annum for both sections, or 5s. for either the Physics or the Electrical Engineering Section, and by all other members of The Institution at 20s. for both Sections, or 12s. 6d. for either Section alone, the rates charged to the general public being £1 15s. per Section, or £3 for both Sections.

(46) BENEVOLENT FUND

The donations and subscriptions to the Fund in 1937 amounted to £3 031 9s. 4d. in which amount are included the proceeds of Golf Competitions organized by the Mersey and North Wales (Liverpool) Centre (£120), the North-Western Centre (£99 15s.), the Scottish Centre (£11 16s. 6d.), and the Incorporated Municipal Electrical Association (£21). In addition to the foregoing, the Fund benefited by the surplus of £244 4s. 1d. on the Electrical Engineers' Ball for 1937, and gifts were received from the organizers of similar functions in the provinces (£65 from the South Midland Electrical Engineers' Ball, £15 15s. from the North-Western Centre Manchester Engineers' Dance Committee, and £5 5s. from the South Midland Centre Students' Ball). A legacy of £50 was received by the Fund from the estate of the late Mr. J. D. Dallas. Full details are shown in the Accounts of the Fund for 1937.

In the course of 1937, grants amounting to a total of £4 434 3s. 7d. were made to 73 persons. In assisting these cases the Fund also provided for the necessities of 69 dependants.

During the last few years the annual totals of the grants made have shown a marked increase and the expenditure in 1937 has exceeded the subscriptions to the Fund by an amount of £1 402 14s. 3d. This position is causing the Committee of Management much anxiety, and the Council earnestly hope that all members of The Institution will give the Fund their continued support, in order that the demands on its resources may be adequately met. Out of a total membership of 18 252 only 5 569 members subscribe to the Fund, and the Council appeal to the remaining members to send donations or promises of annual subscriptions of any amount, which will be gratefully received.

The Committee wish to express great appreciation to the Local Honorary Treasurers for their efforts in stimulating an active interest in the Fund among the members in the Local Centres, and their valuable assistance in the investigation of applications.

Electrical Engineers' Ball.

The Ball, which was held at Grosvenor House, Park Lane, on Friday, the 11th February, 1938, was again most successful, and the Fund benefited by receiving the whole of the surplus of £202. Cordial thanks are due to the General and Executive Committees of the Ball and the stewards for their valuable assistance.

(47) THE INSTITUTION AND BODIES ON WHICH IT IS REPRESENTED

Appendix C (page 865) shows in diagrammatic form the organization of The Institution and the bodies on which it is represented.

APPENDIX A

Membership of The Institution

The changes in the membership since the 1st April, 1937, are shown in the following table:—

	Hon. Mem.	Mem.	Assoc. Mem.	Com.	Assoc.	Grad.	Stud.	TOTAL
Totals at 1 April, 1937	15	2 018	6 809	106	1 357	4 221	2 873	17 399
Additions during the year:—								
Elected	1	6	149	3	80	320	1 000	1 559
Reinstated	—	1	6	—	1	4	9	21
Transferred to ..	—	98	307	—	7	471	—	883
Totals..	1	105	462	3	88	795	1 009	2 463
Deductions during the year:—								
Deceased ..	1	39	42	1	11	7	4	105
Resigned ..	—	8	52	2	13	60	59	194
Lapsed ..	—	6	55	—	25	87	255	428
Transferred from ..	—	—	97	—	30	276	480	883
Totals..	1	53	246	3	79	430	798	1 610
Net Increase ..								853
Totals at April, 1938	15	2 070	7 025	106	1 366	4 586	3 084	18 252

APPENDIX B

Meetings

The following is a list of the meetings held during the past 12 months:—

Ordinary Meetings ..	17
Annual General Meeting ..	1
Annual General Meeting (Benevolent Fund) ..	1
Wireless Section ..	9
Meter and Instrument Section ..	9
Transmission Section	7
Informal Meetings ..	12
Council Meetings ..	15
Local Centres:—	
Irish ..	9
Mersey and North Wales (Liverpool)	12
North-Eastern ..	15
North Midland ..	15
North-Western ..	14
Scottish ..	13
South Midland ..	12
Western ..	12
Local Sub-Centres:—	
Devon and Cornwall	3
Dundee ..	6
East Midland ..	9
Hampshire ..	8
Northern Ireland ..	9
Sheffield ..	7
Tees-Side ..	8
West Wales (Swansea) ..	6
Students' Sections:—	
Bristol ..	8
Liverpool ..	13
London ..	15
North-Eastern ..	16
North Midland ..	13
North-Western ..	10
Scottish ..	10
Sheffield ..	8
South Midland ..	13
Committees:—	
Benevolent Fund ..	9
Electrical Engineers' Ball ..	5
Committees—*continued*.	
Education and Examinations ..	7
Finance ..	10
General Purposes (and Sub-Committees) ..	14
H.T. Conference, Paris (British National Committee)	2
Informal Meetings	7
Local Centres ..	1
Membership ..	9
Meter and Instrument Section (and Sub-Committees)	22
Model General Conditions ..	1
National Certificates (England)	4
National Certificates (Scotland)	2
Overseas Activities	1
Papers (and Sub-Committees) ..	10
Scholarships ..	2
Science Abstracts (and Sub-Committee) ..	5
Ship Electrical Equipment (and Sub-Committees)	20
Transmission Section (and Sub-Committees) ..	16
Wireless Section (and Sub-Committees) ..	17
Wiring Regulations (and Sub-Committees) ..	41
Other Committees	17
Total ..	575

APPENDIX C

THE INSTITUTION OF ELECTRICAL ENGINEERS

- Ordinary Meetings
- Wireless Section Meetings
- Meter and Instrument Section Meetings
- Transmission Section Meetings
- Informal Meetings
- Meetings of London Students' Section
- COUNCIL
- *Local Centres.*
  - Argentine
  - China
  - Irish
  - Mersey and North Wales (Liverp'l)
    - Mersey and North Wales (Liverp'l) S.S.
  - North-Eastern
    - Tees-Side S.C.
    - North-Eastern S.S.
  - North Midland
    - Sheffield S.C.
    - North Midland S.S.
    - Sheffield S.S.
  - North-Western
    - North-Western S.S.
  - Scottish
    - Dundee S.C.
    - Scottish S.S.
  - South Midland
    - East Midland S.C.
    - South Midland S.S.
  - Western
    - Devon and Cornwall S.C.
    - West Wales (Swansea) S.C.
    - Bristol S.S.
- Hampshire S.C.
- Northern Ireland S.C.

NOTE.—S.C. denotes a Sub-Centre, and S.S. a Students' Section.

COMMITTEES OF COUNCIL

Education and Examinations
Finance
General Purposes
Library and Museum
Membership
Papers

SPECIAL COMMITTEES

Benevolent Fund
Earthing to Water Mains (Joint)
Electrical Engineers' Ball
Electricity (Supply) Regulations
Faraday Medal and Honorary Membership Advisory
Informal Meetings
International Relations
Local Centres
Meter and Instrument Section
Model General Conditions
Overseas Activities
Patent Law
Scholarships
Science Abstracts
Ship Electrical Equipment Regulations
Transmission Section
Wireless Section
Wiring Regulations

Technical Committees.

Applications and Plant
Electricity in Mines
Electrochemistry and Electrometallurgy
Power Stations and their Equipment
Radiological and Electromedical Apparatus
Telegraphs and Telephones
Traction, including Railways

Overseas Committees.

Ceylon
India (Bombay, Calcutta, Lahore, and Madras)
New South Wales
Queensland
South Australia
Victoria and Tasmania
Western Australia
New Zealand
Transvaal

BODIES ON WHICH THE INSTITUTION IS REPRESENTED

Bristol University
British Cast Iron Research Association
British Electrical and Allied Industries Research Association
British Electrical Development Association, Committee on Rural and Agricultural Electrification
British National Illumination Committee of the International Illumination Commission
British Standards Institution
Building Industries National Council (Advisory Committee on Building Acts and Bye-laws and Committee on Magnesite Composition Floors and Dadoes)
City and Guilds of London Institute
Council for the Preservation of Rural England
Electrical Association for Women
Electricity Commission, Conference on Rural Electrification
Engineering Joint Council
Engineering Public Relations Committee
H.T. Conference, Paris, British National Committee
Imperial College of Science and Technology, Governing Body
Imperial Minerals Resources Conference, Copper Committee
Institute of Industrial Administration, Examinations Advisory Council
Institute of Metals, Corrosion Research Committee
Institution of Civil Engineers, Engine and Boiler Testing Committee
Institution of Civil Engineers, Earthing to Water Mains Sub-Committee
International Association for Testing Materials
International Electrotechnical Commission, British National Committee
Joint Committee on Materials and their Testing
Joint Committee of The Institution of Civil Engineers and the E.R.A. for research on Earthing to Water Mains
Joint Fuel Committee
League of Nations Health Organization, Committee on Health and Comfort Conditions in Housing
Loughborough Technical College, Advisory Committee
Manchester Regional Advisory Council for Technical and other forms of Further Education
Metalliferous Mining (Cornwall) School, Governing Body
National Certificates and Diplomas in Electrical Engineering, Joint Committees for
National Committee on Physics (Royal Society)
National Committee on Scientific Radio (Royal Society)
National Physical Laboratory, General Board
National Register of Electrical Installation Contractors
National Smoke Abatement Society
Professional Classes Aid Council
Royal Engineer Board
Science Museum, South Kensington, Advisory Council
Town Planning Institute, Committee on Overhead Transmission Lines
Union of Lancashire and Cheshire Institutes, Panel for Engineering
University College, Nottingham, Electrical Engineering Advisory Committee
War Office Mechanization Board
Women's Engineering Society
World Power Conference, British National Committee

THE INSTITUTION OF ELECTRICAL ENGINEERS

REVENUE ACCOUNT FOR THE YEAR ENDED 31st DECEMBER, 1937.

Dr.

EXPENDITURE.

Year ended 31 Dec., 1936* £ s. d.		£ s. d.	£ s. d.
	To MANAGEMENT:—		
	Salaries and Wages	16,974 13 1	
	Staff Provident Scheme	1,376 7 7	
	National Insurance	129 12 2	
	Audit Fee	99 15 0	
	Printing	1,096 0 7	
	Stationery and Office Requisites	949 12 2	
	Addressing Machine Requisites	50 12 1	
	Postage of Correspondence and Notices	1,049 7 4	
	Telephone	127 17 11	
	Travelling Expenses	267 2 8	
20,505 7 2			22,121 0 7
	,, INSTITUTION BUILDING:—		
	Ground Rent	2,201 0 0	
	Rates	3,160 2 10	
	Heating	1,274 11 6	
	Lighting and Power	487 17 10	
	Insurance	215 13 7	
	Transferred to Repairs Suspense Account	1,000 0 0	
	Kitchen Electrical Apparatus	110 19 5	
	Decorations for Coronation of H.M. King George VI	94 10 0	
	Household Requisites and Cleaning	592 11 1	
		9,137 6 3	
	Less Rents from Tenants	5,525 0 0	
8,540 7 0			3,612 6 3
383 1 5	,, FURNITURE AND FITTINGS (Repairs and Renewals)		672 19 1
	,, JOURNAL:—		
	Printing	7,684 9 0	
	Postage	3,178 6 10	
	Wrappers and Envelopes	409 7 2	
		11,272 3 0	
	Less Sales and Advertisements	3,964 15 7	
6,566 18 9			7,307 7 5
70 11 3	,, PROCEEDINGS OF THE WIRELESS SECTION (Printing, Postage, etc.: *less* Sales)		65 15 0
562 6 11	,, STUDENTS' QUARTERLY JOURNAL (Editing, Printing, Postage, etc.: *less* Sales)		572 17 6
180 12 11	,, LENDING LIBRARY (Books, Printing, Postage, etc.)		124 14 11
	,, SCIENCE ABSTRACTS:—		
	Abstracting, Editing, Printing, Postage, etc.	5,766 19 2	
	Less Subscriptions, Sales and Advertisements	5,328 5 2	
500 18 0			438 14 0
	Carried Forward		£34,915 14 9

INCOME.

Year ended 31 Dec., 1936. £ s. d.		£ s. d.	£ s. d.
43,306 12 8	By SUBSCRIPTIONS		45,026 1 9
1,275 15 0	,, ENTRANCE FEES		1,317 15 0
105 10 0	,, LIFE COMPOSITIONS		78 16 2
5,924 10 10	,, DIVIDENDS AND INTEREST		5,785 6 4
128 18 10	,, SALES OF "MODEL GENERAL CONDITIONS"		115 8 11
186 14 0	,, SALES OF "WIRING REGULATIONS"		164 17 3
5 0 9	,, SALES OF "SHIP WIRING REGULATIONS"		4 19 5
	,, EXAMINATIONS:—		
	Graduateship Examination (Candidates' Fees and Sale of Papers, *less* Examiners' Fees, Printing, etc.)	633 1 5	
	National Certificates and Diplomas (Candidates' and School Authorities' Fees, *less* Assessors' Fees, Stationery, Postage, Travelling Expenses, etc.)	800 5 5	
1,426 4 0			1,433 6 10
	Carried Forward		£53,926 11 8

REVENUE ACCOUNT—*continued.*

Dr. EXPENDITURE—*continued.*

1936*		£ s. d.	£ s. d.
	Brought Forward		.. 34,915 14 9
	To INSTITUTION MEETINGS:—		
	Advance Proofs	276 2 10	
	Reporting	162 15 0	
	Grant to London Students' Section	61 9 0	
	Honorarium to Kelvin Lecturer ..	25 0 0	
	Refreshments, Assistance, etc. ..	479 6 11	
	Travelling Expenses of Authors of Papers	106 19 5	
	Overseas Meetings	104 5 1	
1,292 0 5			1,215 18 3
	,, LOCAL CENTRES:—		
	Money Grants	3,750 19 10	
	Travelling Expenses	748 11 5	
	Faraday Lectures	541 13 2	
	Students' Lectures	145 19 6	
5,006 13 0			5,187 3 11
328 17 9	,, PREMIUMS FOR PAPERS		308 19 9
1,389 17 10	,, SCHOLARSHIPS		1,372 5 5
	,, SPECIAL GRANTS:—		
	British Standards Institution ..	1,000 0 0	
	Electrical Research Association ..	1,000 0 0	
	National Illumination Committee ..	32 0 0	
	International Electrotechnical Commission, Plenary Meeting in 1938 (2nd instalment)	350 0 0	
	Paris Conference on High Tension Systems	71 6 6	
	Engineering Public Relations Committee	145 0 0	
	World Power Conference	100 0 0	
	Joint Committee on Materials and their Testing	10 0 0	
	International Commission on Telephonic Interference	14 0 5	
	British Association for the Advancement of Science, Indian Delegation Fund	50 0 0	
2,544 13 11			2,772 6 11
—	GRAHAM BELL MEMORIAL TABLET AT EDINBURGH		21 3 0
87 9 2	,, ANNUAL DINNER		132 19 5
691 15 0	,, CONVERSAZIONES		675 13 8
157 11 0	,, LEGAL EXPENSES		94 10 0
135 10 9	,, MISCELLANEOUS EXPENSES		141 13 9
48,968 12 3			46,838 8 10
	,, AMOUNT TRANSFERRED TO SINKING FUND (Premiums for Redemption		
277 12 2	,, of Cost of Building and Lease) ..	277 12 2	
3,113 1 8	,, **Balance carried to Balance Sheet** ..	6,810 10 8	
3,390 13 10			7,088 2 10
52,359 6 1			£53,926 11 8

Cr. INCOME—*continued.*

1936		£ s. d.
	Brought Forward	.. 53,926 11 8
52,359 6 1		£53,926 11 8

* This column does not add up to the total of Expenditure shown, as some of the items in the accounts for 1936 did not occur in 1937.

BALANCE SHEET, 31st DECEMBER, 1937.

Dr. LIABILITIES.

	£	s.	d.	£	s.	d.
To Uninvested Balances of Trust Funds				438	9	6
,, Sundry Creditors				6,239	10	8
,, Subscriptions received in advance				938	0	11
,, Repairs Suspense Account:—						
Balance at 1st January, 1937	3,900	18	4			
Amount set aside in 1937	1,000	0	0			
	4,900	18	4			
Less Expenditure on Repairs in 1937	636	6	1			
				4,264	12	3
Carried Forward				£11,880	13	4

ASSETS. **Cr.**

	£	s.	d.	£	s.	d.
By Institution Building and Lease:—						
Cost	73,028	6	10			
Less Reserve for Depreciation, being Surrender Values of Sinking Fund Policies	10,922	0	8			
				62,106	6	2
,, Sinking Fund (Surrender Values of Policies for Redemption of Cost of Building and Lease)				10,922	0	8
,, Library (exclusive of the Ronalds Library and Faraday Papers, which are held in trust):—						
As per last Balance Sheet	1,953	6	6			
Additions in 1937	260	9	3			
	2,213	15	9			
Less Depreciation (10 %)	221	7	7			
				1,992	8	2
,, Thompson Memorial Library (Contribution towards purchase)				1,000	0	0
,, Furniture, Fittings, and Apparatus:—						
As per last Balance Sheet	3,356	3	2			
Less Depreciation (5 %)	167	16	2			
				3,188	7	0
,, Sundry Debtors				2,676	3	3
,, Insurance Premiums and Sundry Payments in Advance				1,222	12	9
,, Stock of Paper, Etc., for Publications				895	9	6
,, Investments (at cost):—						
£2,600 Natal Zululand Railways 3 % Debenture Stock	2,270	12	0			
£1,500 London, Midland and Scottish Railway 4 % Preference Stock	1,513	10	4			
£2,000 Assam Bengal Railways 3 % Stock (1931 or after)	1,548	0	6			
£750 Western Australia 4 % Stock (1942–62)	730	8	3			
£750 Union of South Africa 4 % Stock (1943–63)	742	12	0			
£750 Madras and Southern Mahratta Railway 4 % Debenture Stock (1938)	738	15	6			
Carried Forward	£7,543	18	7	£84,003	7	6

BALANCE SHEET—*continued.*

Dr. LIABILITIES—*continued.*

	£ s. d.	£ s. d.	£ s. d.
Brought Forward			11,880 13 4
To Surplus of Assets over Liabilities:—			
Balance at 1st January, 1937		208,673 14 6	
Excess of Income over Expenditure for 1937 brought forward from Revenue Account		6,810 10 8	
		215,484 5 2	
Less Allocation to Supplementary Superannuation Account	£750 0 0		
Depreciation:—			
Library (*per contra*) ..	£221 7 7		
Furniture, Fittings, and Apparatus (*per contra*)	167 16 2		
		1,139 3 9	
			214,345 1 5
			£226,225 14 9

W. McCLELLAND
Honorary Treasurer.

P. F. ROWELL,
Secretary.

ASSETS—*continued.* **Cr.**

	£ s. d.	£ s. d.
Brought Forward	..	84,003 7 6
By Investments (at cost)—*contd.*		
Brought forward	7,543 18 7	
£35 East Indian Railway "B" Annuity (1953) ..	791 5 4	
£1,500 South Australia 4 % Stock (1940–60) ..	1,494 10 6	
£6,450 3½ % War Stock	6,306 9 0	
£19,375 4 % Funding Loan (1960–90)	15,500 0 0	
£8,700 3½ % Conversion Stock (1961 or after) ..	6,651 3 3	
£11,970 11s. 4 % Consolidated Stock	10,291 6 6	
£1,000 London, Midland and Scottish Railway 5 % Preference Stock (1955)	1,020 4 6	
£4,600 North Metropolitan Power Station 5 % Guaranteed Debenture Stock (1957)	4,588 11 0	
£2,000 London, Midland and Scottish Railway 5 % Redeemable Debenture Stock (1952)	1,982 5 9	
£2,300 East Indian Railway 4½ % Irredeemable Debenture Stock	2,019 13 0	
£5,000 Commonwealth of Australia 5 % Stock (1945–75)	4,964 17 6	
£2,000 Tynemouth Corporation 5% Stock (1947–57)	2,025 4 0	
£2,500 Stoke-on-Trent Corporation 5 % Stock (1948–68)	2,550 6 0	
£3,500 East Indian Railway 3½ % Debenture Stock (1937)	2,475 15 6	
£5,000 Brighton Corporation 4¾% Stock (1945–75)	5,050 8 0	
£2,000 New South Wales 5¼ % Stock (1947–57) ..	2,013 19 0	
£2,600 Kenya Government 4½ % Stock (1950) ..	2,483 4 0	
£3,000 Southern Railway 4 % Debenture Stock ..	2,520 5 0	
£2,500 India 4½ % Stock (1958–68)	2,329 17 9	
£2,500 Corporation of London 4½ % Debenture Stock (1940–85)	2,462 14 0	
£3,000 Birmingham Corporation 4½ % Stock (1948–68)	2,906 11 0	
£3,000 London County 4½ % Stock (1945–85) ..	2,936 11 0	
£1,000 Bootle Corporation 4¾ % Stock (1949–59)	967 12 0	
£10,000 5 % Conversion Stock (1944–64)	9,888 5 10	
£2,000 Southampton Corporation 5 % Stock (1947–67)	2,027 14 0	
£2,333 London Passenger Transport Board 4½ % "A" Stock (1985–2023)	2,110 5 0	
£2,000 Agricultural Mortgage Corporation 5 % Debenture Stock (1959–89)	2,080 11 0	
£2,400 Ayr County Council 5 % Stock (1947–57)	2,484 4 0	
£2,400 Union of South Africa 5 % Stock (1950–70)	2,436 4 0	
£1,000 Nyasaland Government 4½ % Guaranteed Stock (1952–72)	1,142 13 0	
£2,500 London Passenger Transport Board 5 % "B" Stock (1965–2023)	3,017 1 0	
£5,000 London County 2¾ % Consolidated Stock (1960–70)	4,811 2 6	
£5,600 3 % Funding Loan (1959–69)	5,419 19 0	
(*Market value 31st December*, 1937, £150,017 0s. 9d.) ..		129,294 11 6
,, Cash in Hands of Local Centres on 30 Sept., 1937	..	1,587 18 10
,, Cash:—		
At Bank	891 16 10	
At Banks in Australia and New Zealand	10,360 9 10	
In hands of Secretary	87 10 3	
		11,339 16 11
		£226,225 14 9

We beg to report that we have audited the Balance Sheet of The Institution of Electrical Engineers, dated 31st December, 1937, and above set forth, together with the annexed Statements of Account. We have obtained all the information and explanations we have required. In our opinion the Statements are correct and the Balance Sheet is properly drawn up so as to exhibit a true and correct view of the state of The Institution's affairs according to the best of our information and the explanations given to us and as shown by the books of The Institution.

ALLEN, ATTFIELD & CO., *Auditors.*
Chartered Accountants,
24, Martin Lane, Cannon Street, E.C.4.

27th April, 1938.

SALOMONS SCHOLARSHIP TRUST FUND (Capital).

Dr.	£ s. d.	Cr.	£ s. d.
To Amount (as per last Account)	2,085 1 4	By Investments (at cost):—	
		£1,600 13s. 3d. Commonwealth of Australia 3% Stock (1955–58)	1,585 1 4
		£500 Cardiff Corporation 3% Stock (1952–55)	500 0 0
	£2,085 1 4		£2,085 1 4

SALOMONS SCHOLARSHIP TRUST FUND (Income).

Dr.	£ s. d.	Cr.	£ s. d.
To Amount paid to Scholars in 1937	100 0 0	By Dividends received in 1937	55 17 0
		,, Contribution from Institution	44 3 0
	£100 0 0		£100 0 0

DAVID HUGHES SCHOLARSHIP TRUST FUND (Capital).

Dr.	£ s. d.	Cr.	£ s. d.
To Amount (as per last Account)	2,000 0 0	By Investment (at cost):—	
		£2,045 Metropolitan Water Board (Staines Reservoirs) 3% Guaranteed Debenture Stock (1922 or after)	1,998 15 0
		,, Balance carried to Balance Sheet*	1 5 0
	£2,000 0 0		£2,000 0 0

DAVID HUGHES SCHOLARSHIP TRUST FUND (Income).

Dr.	£ s. d.	Cr.	£ s. d.
To Amount paid to Scholars in 1937	100 0 0	By Dividends received in 1937	53 13 7
		,, Interest received in 1937	0 0 6
		,, Contribution from Institution	46 5 11
	£100 0 0		£100 0 0

PAUL SCHOLARSHIP FUND (Capital).

Dr.	£ s. d.	Cr.	£ s. d.
To Amount (as per last Account)	1,000 0 0	By Investments (at cost):—	
		£625 4% Funding Loan (1960–90)	500 0 0
		£518 3s. 8d. Central Electricity Board 5% Debenture Stock (1950–70)	500 0 0
	£1,000 0 0		£1,000 0 0

PAUL SCHOLARSHIP FUND (Income).

Dr.	£ s. d.	Cr.	£ s. d.
To Amount paid to Scholars in 1937	50 0 0	By Balance (as per last Account)	23 8 3
,, Balance carried to Balance Sheet*	21 1 8	,, Dividends received in 1937	47 13 5
	£71 1 8		£71 1 8

* Included in the total of £438 9s. 6d. shown on the Liabilities side of the Balance Sheet.

WILDE BENEVOLENT TRUST FUND (Capital).

Dr.	£	s.	d.	Dr.	£	s.	d.
To Amount (as per last Account)	3,049	16	2	By Investments (at cost):—			
				£1,308 London and North Eastern Railway 4% First Guaranteed Stock	1,744	3	11
				£100 London County 2¾% Consolidated Stock (1960–70)	101	8	6
				£250 New South Wales 4% Stock (1942–62)	251	6	0
				£500 3½% War Stock	501	9	3
				£381 15s. 1d. 4% Funding Loan (1960–90)	300	0	0
				£200 3½% Conversion Stock (1961 or after)	151	8	6
	£3,049	16	2		£3,049	16	2

WILDE BENEVOLENT TRUST FUND (Income).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Grants made in 1937	104	0	0	By Balance (as per last Account)	29	3	0
,, Balance carried to Balance Sheet*	22	10	3	,, Dividends received in 1937	97	0	10
				,, Interest received in 1937	0	6	5
	£126	10	3		£126	10	3

WAR THANKSGIVING EDUCATION AND RESEARCH FUND (No. 1) (Capital).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Amount (as per last Account)	1,700	0	0	By Investment (at cost):—			
				£2,000 3½% War Stock	1,700	0	0
	£1,700	0	0		£1,700	0	0

WAR THANKSGIVING EDUCATION AND RESEARCH FUND (No. 1) (Income).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Balance (as per last Account)	5	0	0	By Dividends received in 1937	70	0	0
,, Grants made in 1937	12	10	0				
,, Balance carried to Balance Sheet*	52	10	0				
	£70	0	0		£70	0	0

PAGE PRIZE FUND (Capital).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Amount (as per last Account)	100	19	5	By Investments (at cost):—			
				£50 3½% War Stock	50	19	5
				£51 16s. 4d. Central Electricity Board 5% Debenture Stock (1950–70)	50	0	0
	£100	19	5		£100	19	5

PAGE PRIZE FUND (Income).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Balance carried to Balance Sheet*	15	0	2	By Balance (as per last Account)	10	19	10
				,, Dividends received in 1937	4	0	4
	£15	0	2		£15	0	2

THORROWGOOD SCHOLARSHIP TRUST FUND (Capital).

Dr.	£	s.	d.	Cr.	£	s.	d.
To Amount (as per last Account)	1,000	0	0	By Investment (at cost):—			
				£1,005 Agricultural Mortgage Corporation 5% Debenture Stock (1959–89)	1,000	0	0
	£1,000	0	0		£1,000	0	0

* Included in the total of £438 9s. 6d. shown on the Liabilities side of the Balance Sheet.

Dr. THORROWGOOD SCHOLARSHIP TRUST FUND (Income). Cr.

	£	s.	d.		£	s.	d.
To Amount paid to Scholars in 1937	50	0	0	By Balance (as per last Account)	58	0	8
,, Balance carried to Balance Sheet*	52	0	1	,, Dividends received in 1937	43	19	5
	£102	0	1		£102	0	1

Dr. SWAN MEMORIAL SCHOLARSHIP FUND (Capital). Cr.

	£	s.	d.		£	s.	d.
To Amount (as per last account)	2,968	12	4	By Investments (at cost):—			
				£1,000 Sunderland Corporation 5% Stock (1946–56)	1,116	13	0
				£640 Sunderland Corporation 5% Stock (1950–60)	728	8	0
				£1,135 17s. 9d. 3½% Conversion Stock (1961 or after)	1,123	11	4
	£2,968	12	4		£2,968	12	4

Dr. SWAN MEMORIAL SCHOLARSHIP FUND (Income). Cr.

	£	s.	d.		£	s.	d.
To Amount paid to Scholars in 1937	120	0	0	By Balance (as per last Account)	23	1	8
,, Balance carried to Balance Sheet*	9	12	4	,, Dividends received in 1937	106	10	8
	£129	12	4		£129	12	4

Dr. WILLIAM BEEDIE ESSON SCHOLARSHIP TRUST FUND (Capital). Cr.

	£	s.	d.		£	s.	d.
To Amount (as per last Account)	3,006	2	6	By Investments (at cost):—			
				£1,500 3½% War Stock	1,603	2	6
				£200 New Zealand 5% Stock (1949) ..	233	0	0
				£250 St. Helen's Corporation 5% Stock (1950–70)	293	15	0
				£250 Sunderland Corporation 5% Stock (1950–60)	293	15	0
				£250 Birmingham Corporation 5% Stock (1946–56)	291	5	0
				£250 Grimsby Corporation 5% Stock (1950–60)	291	5	0
	£3,006	2	6		£3,006	2	6

Dr. WILLIAM BEEDIE ESSON SCHOLARSHIP TRUST FUND (Income). Cr.

	£	s.	d.		£	s.	d.
To Amount paid to Scholar in 1937	30	0	0	By Balance (as per last Account)	135	8	10
,, Balance carried to Balance Sheet*	211	11	4	,, Dividends received in 1937	106	2	6
	£241	11	4		£241	11	4

Dr. SUPPLEMENTARY SUPERANNUATION ACCOUNT. Cr.

	£	s.	d.		£	s.	d.
To Amount (as per last Account)	2,384	9	2	By Investment (at cost):—			
,, Amount allocated in 1937	750	0	0	£3,024 16s. 6d. 3½% War Stock	3,180	0	11
,, Dividends received in 1937	98	10	5	,, Balance carried to Balance Sheet*	52	18	8
	£3,232	19	7		£3,232	19	7

* Included in the total of £438 9s. 6d. shown on the Liabilities side of the Balance Sheet.

TAXATION OF ELECTRICITY UNDERTAKINGS*

By G. V. HARRAP, Associate Member.

(ABSTRACT *of paper read before the* NORTH MIDLAND STUDENTS' SECTION, *3rd November*, 1936.)

SUMMARY

The taxation of electricity undertakings broadly resolves itself into two components, viz. local rates and income tax. The main principles given in Acts and legal decisions are explained, together with their application and incidence. The conclusion is reached that strict comparison of incidence is impossible, although a simpler method of valuation and assessment would be valuable.

LOCAL RATES

Rateable Value

The 1601 Act originated local rates, but the Act of 1836, since followed by the Act of 1925, Section 22 (1) (*b*), is now the main authority. Valuations are made every five years, but rating authorities can make adjustments in the interim. The next valuations occur in 1939,† and hence the importance of appreciating all the implications; the author feels it would pay undertakings to employ an engineer specially skilled in accountancy for this work.

Electricity undertakings are not mentioned in taxation enactments, few legal decisions involve them, and explanatory literature is scarce. The general law has to be consulted for guidance, and cases on other public utility undertakings have to be followed for the application of principles.

The old valuation basis was "personal means," but is now the rent at which the hereditament would let from year to year if the tenant undertook repairs, insurance, etc. This "rent" is obtained from the revenue account, but all receipts accruing to a hypothetical landlord, such as rents received, are disallowed. Normal expenditure is deducted from revenue, but wayleave rentals, capital expenditure from revenue, etc., are excluded. Depreciation, obsolescence, and sinking funds, are assessed at those amounts necessary to maintain the buildings and equipment in a state to command rent, and actual transfers to special accounts are ignored. The plant, etc., is valued on a pre-war basis, plus a percentage for present-day replacement cost. Plant for future expansion is omitted from these calculations, since hypothetical tenants are concerned only with present needs.

The tenant needs capital to make payments for fuel and other charges until consumers' remittances are received; interest and profit is allowed on this. To exclude extraordinary repairs a three-year average is taken, and the final result is the rateable value (plus rates) of the undertaking.

Apportionment

To apportion the undertaking's rateable value among parishes, indirectly productive portions (power and sub-stations, transmission lines, etc.) are valued on a pre-war basis, plus a percentage for present cost. Subtracting this value from the total leaves the rateable value (plus rates) of the directly productive portion. These latter are in contact with consumers, and are apportioned in the ratio of receipts obtained from the parish. Using a factor to eliminate rates, and adding the rateable value of the indirectly productive items, gives the total rateable value of the undertaking in each parish. Varying poundages are then levied on the values obtained.

Another valuation method is to deduct from the total the directly rateable items, and divide the balance between indirectly and directly productive items. From this the percentage which the balance bears to the indirectly productive items is applied to the cost of works in each parish. The remainder is apportioned by applying to the parish revenue the percentage which the balance bears to the total.

In the original paper, tables were included; these have been omitted from this abstract, but reference should be made to a paper by E. W. Booth.†

Incidence

When considering incidence it is difficult to select a proper basis. To eradicate varying rate-poundages, curves of rateable value plotted against revenue (which is the professed basis of valuation) for undertakings segregated into generating and other local authorities and companies within the London and Home Counties Joint Electricity Authority's area, show great variations. Similar variations occur when using capital expenditure‡ or gross surplus, which are other possible bases when considering hypothetical rent.

Reference to the Electricity Commissioners' Annual Reports shows similar inequalities over the whole country. The amount of valuation varies with locality and local policies, i.e. high rateable value and low poundage, or low rateable value and high poundage, can produce the same result.

INCOME TAX

Assessment

This tax is, theoretically, not a permanent one, but is an annual tax imposed and collected by virtue of an annual Act of Parliament.§ The amount of this tax is fixed on the basis of the Income Tax Consolidation Act, 1918, which re-enacted the provisions of the Acts of 1806 and 1853. Electricity undertakings are assessed under Case 1 of Schedule D of the 1918 Act, although certain portions, such as power stations and substations, come under Schedule A. The provisions of Schedule D apply

* The original paper, of which this is an abstract, was awarded a Students' Premium by the Council.

† Parliament has now decided to defer this until 1941.

† See Bibliography, (5). ‡ *Ibid.*, (2). § *Ibid.*, (6) and (8).

to manufacturing and other competitive concerns, and modifications are required for the assessment of quasi-monopolistic undertakings.

Again, the revenue account is used to ascertain profits, but instead of depreciation, "wear and tear" allowances are made at varying percentages on written-down value. If the profits are insufficient to stand the full allowance, undertakings can carry the excess forward, and, should profits be less than interest charges, tax is charged on interest, the difference being "depreciation-in-hand." Rebates are granted for obsolescence, but repairs are only allowed where no capital improvement is made. Interest on loans, etc., is disallowed even though enforced by statute. Only sufficient publicity charges to maintain the business are permitted, while increases in assessment are made for profits on supplies to non-trading departments of local authorities. Credits are allowed where deductions cannot be computed in time for assessment.

Incidence

Since this tax is a prior charge before dividends, comparison with gross surplus is reasonable. This has been done for those undertakings used in the comparison of local rates, but wide variations are apparent. Comparison with revenue shows still wider inequalities.* It is not suggested, however, either here or in the case of local rates, that undertakings should have a common upper limit; rather the reverse.

Some explanation of these variations is given by the statutory deductions, since different distributions of revenue, either designed or accidental, will produce varying assessments.

CONCLUSIONS

Parliamentary control is an essential feature of taxation, but some amelioration can be obtained by studying its principles.

The unequal incidence of local rates partly results from the application of prescribed methods. Mr. J. N. Waite† gave instances of local rates and suggested a return to a basis allied to income. At present this is only taken into account by implication, and the only way in which the burden can be reduced is to reduce profits and to approximate depreciation and other allowances to statutory deductions.

* See Bibliography, (9).

† *Ibid.*, (4).

Electricity undertakings are excluded from de-rating; their inclusion would reduce the burden, though leaving the inequalities.

With local authorities the elimination of contributions to local rates may be impossible, but reductions can be achieved through contraction of outstanding debt, since such contributions are limited to $1\frac{1}{2}$ % of this debt.

Income tax is more intractable, and its reduction again rests on profit and statutory deductions.

Non-statutory undertakings are subject to other taxes, but they form only a small part of the industry.*

Acknowledgment is made to sources in the Bibliography, and to others. Thanks are due to Mr. J. N. Waite and Mr. S. R. Siviour, Members, for help and encouragement, and to Mr. D. Bellamy for helpful criticisms.

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(3) Konstam: "Modern Law of Rating," 1927.
(4) J. N. Waite: "Rating Law and Practice, with Special Reference to Electricity Undertakings," *Journal I.E.E.*, 1934, vol. 74, p. 60.
(5) E. W. Booth: "Rating Valuations of Public Utility Undertakings," 1933.

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(10) G. V. Harrap: "Non-Statutory Undertakings," *ibid.*, 1937, vol. 121, p. 780.
(11) G. V. Harrap: "Retirements," *ibid.*, 1938, vol. 123, p. 249.
(12) G. V. Harrap: "A.R.P. and Taxation Relief," *ibid.*, 1938, vol. 123, p. 457.

* See Bibliography, (10), for further details.

PROCEEDINGS OF THE INSTITUTION

924TH ORDINARY MEETING, 3RD FEBRUARY, 1938

Sir George Lee, O.B.E., M.C., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 20th January, 1938, were taken as read and were confirmed and signed.

A list of candidates for election and transfer, approved by the Council for ballot, was taken as read and was ordered to be suspended in the Hall.

The President announced that, during the month of January, 3 494 donations and subscriptions to the Benevolent Fund had been received, amounting to £1 691. A vote of thanks was accorded to the donors.

A paper by Mr. E. T. Norris, Member, entitled "The Moving-Coil Voltage Regulator" (see page 1), was read and discussed. The paper was accompanied by a demonstration of apparatus.

A vote of thanks to the author, moved by the President, was carried with acclamation.

925TH ORDINARY MEETING, 24TH FEBRUARY, 1938

Sir George Lee, O.B.E., M.C., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 3rd February, 1938, were taken as read and were confirmed and signed.

A list of candidates for election and transfer, approved by the Council for ballot, was taken as read and was ordered to be suspended in the Hall.

Messrs. R. A. Smith and K. A. H. Slater were appointed scrutineers of the ballot for the election and transfer of members and, at the end of the meeting, the President reported that the members whose names appeared on the list (see vol. 82, page 330) had been duly elected and transferred.

The following papers were read and discussed: "The Electrical Ignition of Mixtures of Ether Vapour, Air, and Oxygen" (see page 145), by Prof. W. M. Thornton, O.B.E., D.Sc., D.Eng., Past-President; and "The Risk of Explosion due to Electrification in Operating Theatres of Hospitals" (see page 156), by E. H. Rayner, M.A., Sc.D., Member. Both papers were accompanied by demonstrations.

A vote of thanks to the authors, moved by the President, was carried with acclamation.

926TH ORDINARY MEETING, 10TH MARCH, 1938

Sir George Lee, O.B.E., M.C., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 24th February, 1938, were taken as read and were confirmed and signed.

The President announced that, during the month of February, 745 donations and subscriptions to the Benevolent Fund had been received, amounting to £276. A vote of thanks was accorded to the donors.

Messrs. P. Harris and A. G. Porter were appointed scrutineers of the ballot for the election and transfer of members and, at the end of the meeting, the President reported that the members whose names appeared on the list (see vol. 82, page 443), had been duly elected and transferred.

The President then presented, amid prolonged applause, the Faraday Medal to Sir John Snell, G.B.E., Honorary Member. In doing so he said: "Sir John Snell is the acknowledged head of the electricity supply industry in this country, to which industry he has devoted his life and his talents. His crowning achievement is the grid. It was his conception and he has now the supreme satisfaction of knowing that it is fully established, with all its advantages, as a great national asset. As Chairman of the Electricity Commission for the long period of 18 years, he has established and maintained the traditions of that high office in an outstanding manner, and in a way which has earned him the thanks and appreciation of a very wide circle in Government, business, and domestic spheres. If I were to enumerate all that Sir John has accomplished in his contribution to the science and practice of electrical engineering, it would absorb much more time than I have at my disposal. He has contributed handsomely to the literature on electrical engineering, and the report of the Water Power Resources Committee, of which he was Chairman, is a standard work of reference. I should like to conclude by wishing—and I am sure that you will all join me in this wish—that he may enjoy good health in his retirement. I now have very great pleasure in presenting the Faraday Medal to Sir John Snell."

Sir John Snell: In 1914–15 The Institution elected me as its President. Two years ago it conferred another honour upon me by making me one of its Honorary Members; and to-night it has capped those former distinctions by awarding me the Faraday Medal—a trinity of distinctions of which any member of this great Institution might be justly proud. The President has alluded to the services which I have endeavoured to render to the industry. It is true that during the last 18 or 20 years my energy has been devoted to the work of the electrical industry, and particularly the electrical supply industry. I have, in the words of Milton, learned to "scorn delights and live laborious days," but it would

be manifestly unfair on my part if I did not say publicly that such work as has been accomplished has been the work of a team, and that the past and present Commissioners and the past and present members of the staff who have rendered me such loyal and whole-hearted co-operation must be held with myself to be responsible for such work as may have been successfully done. The President has also alluded to the creation of the grid. I know that there are divided opinions as to that piece of work, but I think one thing can be claimed by the Electricity Commissioners and by the Central Electricity Board, namely that the great work of engineering which was carried out by the Board—not by the Commissioners—enabled our larger manufacturers to construct such machinery and such well-equipped lines, switchgear, and controlling devices, that our industry has been placed in the very forefront of the manufacturing industries throughout the world, and our electrical manufacturers to-day can vie with any electrical manufacturers in any other country. It is only some 6 or 7 years ago that we celebrated the centenary of Michael Faraday's great fundamental discovery of electromagnetic induction. Those of us who have read of Faraday know that not only was he a great philosopher, a painstaking experimenter, and a great scientist, but he was also a man of kindly nature with a simple faith in the design and wisdom of the Almighty Architect of the universe. I have sometimes wondered whether if, as I believe, we are encompassed by a cloud of unseen witnesses, Faraday may be one of them, and I have wondered what would be his feelings to-day if he could see the great developments which have taken place, all of them dependent upon and flowing from his elementary discovery. It would be unfair for me to trespass further upon the time of this meeting, and unfair to the author of the paper that is to be read. I shall therefore conclude by thanking the President and the Council for the signal honour which they have conferred upon me, and the members present at this meeting for the evident endorsement which they have given to that award.

A paper by Mr. W. J. Jones, M.Sc.(Eng.), Member, entitled "The Lighting Load—its Characteristics and Development" (see page 289) was then read and discussed.

A vote of thanks to the author, moved by the President, was carried with acclamation.

927TH ORDINARY MEETING, 17TH MARCH, 1938

Sir George Lee, O.B.E., M.C., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 10th March, 1938, were taken as read and were confirmed and signed.

A paper by Mr. W. G. Thompson, Ph.D., B.Sc., Associate Member, entitled "Recent Progress in Power Rectifiers and their Applications" (see page 437), was read and discussed.

A vote of thanks to the author, moved by the President, was carried with acclamation.

928TH ORDINARY MEETING, 24TH MARCH, 1938

(Joint Meeting with the Plastics Group of the Society of Chemical Industry)

Sir George Lee, O.B.E., M.C., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 17th March, 1938, were taken as read and were confirmed and signed.

A list of candidates for election and transfer, approved by the Council for ballot, was taken as read and was ordered to be suspended in the Hall.

A paper by Messrs. L. Hartshorn, D.Sc., N. J. L. Megson, M.Sc., and E. Rushton, B.Sc., entitled "Plastics and Electrical Insulation" (see page 474), was read and discussed.

A vote of thanks to the authors, moved by the President, was carried with acclamation.

929TH ORDINARY MEETING, 7TH APRIL, 1938

Sir George Lee, O.B.E., M.C., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 24th March, 1938, were taken as read and were confirmed and signed.

The President announced that, during the month of March, 537 donations and subscriptions to the Benevolent Fund had been received, amounting to £237. A vote of thanks was accorded to the donors.

Messrs. J. W. Rissik and G. B. D. C. Saw were appointed scrutineers of the ballot for the election and transfer of members and, at the end of the meeting, the President reported that the members whose names appeared on the list (see vol. 82, page 563) had been duly elected and transferred.

A paper by Mr. C. E. Fairburn, M.A., Member, entitled "The Trend of Design of Electric Locomotives" (see page 581), was read and discussed.

A vote of thanks to the author, moved by the President, was carried with acclamation.

930TH ORDINARY MEETING, 21ST APRIL, 1938

Sir George Lee, O.B.E., M.C., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 7th April, 1938, were taken as read and were confirmed and signed.

The following papers were read and discussed: " The London Television Service " (see page 729), by Messrs. T. C. Macnamara and D. C. Birkinshaw, M.A.; and " The Marconi-E.M.I. Television System " (see page 758), by Messrs. A. D. Blumlein, B.Sc.(Eng.), Associate Member, C. O. Browne, B.Sc., N. E. Davis, and E. Green, M.Sc., Associate.

A vote of thanks to the authors, moved by the President, was carried with acclamation.

931ST ORDINARY MEETING, 27TH APRIL, 1938

(Joint Meeting with The Institution of Chemical Engineers)

Dr. W. Cullen, President of The Institution of Chemical Engineers, took the chair at 6 p.m.

A paper by Mr. H. J. T. Ellingham, Ph.D., entitled " Electrolysis: Principles of Plant Design and Operation," was read and discussed.*

A vote of thanks to the author, moved by Sir George Lee, O.B.E., M.C. (President, I.E.E.), was carried with acclamation.

932ND ORDINARY MEETING, 28TH APRIL, 1938

Sir George Lee, O.B.E., M.C., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 21st April, 1937, and of the Joint Meeting with the Institution of Chemical Engineers held on the 27th April, 1938, were taken as read and were confirmed and signed.

A list of candidates for election and transfer, approved by the Council for ballot, was taken as read and was ordered to be suspended in the Hall.

Mr. H. J. Allcock, Mr. W. C. P. Tapper, and Dr. W. B. Whitney, were appointed scrutineers of the ballot for the election of new Members of Council.

Professor Max Born, M.A., then delivered the Twenty-Ninth Kelvin Lecture, entitled " Statistical Laws of Nature " (see page 802).

A vote of thanks to the lecturer, proposed by Mr. J. M. Donaldson, M.C., and seconded by Dr. A. P. M. Fleming, C.B.E., was carried with acclamation.

66TH ANNUAL GENERAL MEETING, 12TH MAY, 1938

Sir George Lee, O.B.E., M.C., President, took the chair at 6 p.m.

The notice convening the meeting was taken as read.

The minutes of the Ordinary Meeting held on the 28th April, 1938, were also taken as read and were confirmed and signed.

Dr. W. R. C. Coode-Adams and Mr. P. Harris were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the President reported that the members whose names appeared on the list (see page 143) had been duly elected and transferred.

The list of Premiums (see vol. 82, page 698) awarded by the Council for papers during the session was taken as read.

The President next summarized the Annual Report of the Council (see page 855) and moved its adoption. The motion was seconded by **Mr. W. McClelland, C.B., O.B.E.**

Mr. L. W. Phillips touched upon a number of matters and *inter alia* expressed the opinion that the Report showed a widening of outlook, and he repeated his request (made at previous Annual General Meetings) that an Education Section of The Institution be formed.

After **The President** had mentioned that the Council had considered very fully the suggestions which Mr. Phillips had made at the last Annual General Meeting, the motion for the adoption of the Annual Report was put to the meeting and was carried unanimously.

Mr. W. McClelland (*Hon. Treasurer*), in moving " That the Statement of Accounts and Balance Sheet for the year 1937* as presented be received and adopted," said: " If you refer to the Revenue details on page 867 you will see that the balance carried to the Balance Sheet is £6 810, as compared with £3 113 in 1936—an improvement of £3 697. This improvement is accounted for partly by an increase in income of £1 567, due to the larger membership, and partly by a reduction in expenditure of £2 130.

" On page 866, on the Expenditure side the cost of Management has risen by £1 616, owing mainly to normal increases in salaries and wages and to the extra cost of printing, which includes £400 for a new List of Members. The cost of the Institution Building is considerably less than in 1936, owing to a non-recurring item for a new heating and ventilation system which was erected in 1936 and cost £5 732. The cost of the *Journal* was £740 higher, owing to more copies being printed, more papers being published, and a general rise in the cost of printing and paper. The increase in the cost of repairs and renewals to furniture and fittings, which is quite a small amount—£290—was occasioned by the renewal of the inter-office telephone installation. The remaining items of expenditure compare very favourably with the 1936 figures and appear to call for no special comment.

* The paper and discussion will not be published in the *I.E.E. Journal*, but they will be found in vol. 16 of the *Transactions* of The Institution of Chemical Engineers.

* See page 866.

" Turning now to the Balance Sheet on pages 868 and 869, it will be seen that the total Assets amount to £226 225, and the Liabilities to £11 880, leaving a surplus of Assets over Liabilities of £214 345. This shows an increase of capital for the year of £5 671—a result which I think you will agree is very satisfactory. In addition to the Capital just mentioned, there is an asset of £4 264 held in the Repairs Suspense Account, which constitutes a further reserve.

" If you turn to the Investments on pages 868 and 869, you will see that £5 600 of 3 % Funding Loan was purchased during the year at a cost of £5 419, whilst £200 of North Metropolitan Power Station 5 % Guaranteed Debenture Stock was repaid at par to The Institution. The investments at the end of the financial year stood in the books of The Institution at their cost price of £129 294, and their market value at that date was £150 017. A further valuation was taken at the end of April, 1938, when their value was found to be £149 513, somewhat below the December, 1937, figure, but still more than £20 000 above their cost.

" It will also be seen that The Institution's cash in the banks of Australia and New Zealand now amounts to £10 360. Of this £4 760 is in Australia and £5 600 in New Zealand. My predecessor explained last year that this money cannot be transferred to our funds here except at a heavy loss on exchange. For this reason the money has been placed on fixed deposit and brings in interest at $2\frac{1}{2}$ % per annum.

" I think I have said sufficient to indicate that The Institution continues to enjoy a thoroughly sound position financially, and in submitting the 1937 Accounts for the approval of the members I should like to say how greatly I appreciate the admirable manner in which the Accounts have been prepared."

The motion for the adoption of the Accounts was seconded by **Mr. C. R. Westlake** and, as no member had any observations to make, it was put to the meeting and carried unanimously.

The President then moved " That the best thanks of The Institution be accorded to the following officers for their valuable services during the past year: (*a*) the Hon. Secretaries of the Local Centres; (*b*) the Local Hon. Secretaries abroad; and (*c*) the Hon. Treasurer, Mr. W. McClelland."

The resolution was seconded by **Mr. G. K. Paton** and was carried with acclamation.

Mr. P. P. Wheelwright then moved " That Messrs. Allen, Attfield and Co. be appointed auditors for the year 1938–39." The motion was seconded by **Mr. S. C. Bartholomew** and was carried unanimously.

The meeting then terminated.

933RD ORDINARY MEETING, 12TH MAY, 1938

Sir George Lee, O.B.E., President, took the chair at 6.30 p.m., immediately after the conclusion of the Annual General Meeting.

Dr. A. P. M. Fleming, C.B.E., Vice-President, then delivered the Fourteenth Faraday Lecture, entitled " The Evolution of Electrical Power."

A vote of thanks to the lecturer, moved by the President, was carried with acclamation.

THE BENEVOLENT FUND

40TH ANNUAL GENERAL MEETING, 12TH MAY, 1938.

Sir George Lee, O.B.E., M.C., President, took the chair at 5.30 p.m.

The notice convening the meeting was taken as read. The minutes of the 39th Annual General Meeting held on the 6th May, 1937, were also taken as read and were confirmed and signed.

The Report of the Committee of Management (see below), and the Statement of Accounts for the year 1937 (see page 880), were presented and, on the motion of the chairman, seconded by Mr. L. W. Phillips, were unanimously adopted.

On the motion of the chairman it was resolved that Mr. A. J. Attfield, A.C.A., be appointed Honorary Auditor for the year 1938.

The chairman reported the constitution of the Committee of Management for the year 1937–38 (see vol. 82, page 117).

The meeting then terminated.

REPORT OF THE COMMITTEE OF MANAGEMENT OF THE BENEVOLENT FUND FOR 1937

Capital

The Capital Account stood on the 31st December, 1937, at £23 863 2s. 2d., which is invested.

Receipts

The Income for 1937 from dividends, interest, and annual subscriptions, was as follows:—

	£	s.	d.
Dividends and Interest ..	1 012	15	10
2 148 Annual Subscriptions ..	1 108	5	0
	£2 121	0	10

In addition to the foregoing, the Fund benefited during the year by the following donations:—

Donations

	£	s.	d.
Mersey and North Wales (Liverpool) Centre, Golf Tournament	120	0	0
North-Western Centre, Golf Tournament	105	0	0
South Midland Electrical Engineers' Ball	65	0	0
Western Centre and West Wales Sub-Centre	34	13	4
"The Twenty-Five Club"	26	5	0
Incorporated Municipal Electrical Association	10	10	0
Incorporated Municipal Electrical Association, Golf Tournament	21	0	0
North-Western Centre, Manchester Engineers' Ball	15	15	0
North Midland Centre, collections at meetings	15	18	0
Scottish Centre, Golf Tournament	11	16	6
National Register of Electrical Installation Contractors	10	10	0
South Midland Students' Section Ball	5	5	0
Henley's Telegraph Works Co., Ltd.	25	0	0
General Electric Co., Ltd.	10	10	0
Messrs. Kennedy and Donkin	10	10	0
Messrs. Merz and McLellan	10	10	0
Messrs. Nathan and Allen	5	5	0
H. Marryat	50	0	0
Lord Hirst of Witton	30	5	0
Anonymous	10	10	0
E. R. Elliston	5	12	6
Anonymous	5	5	0
V. B. D. Cooper	5	5	0
S. Evershed	5	5	0
V. E. Faning	5	5	0
F. C. Raphael	5	5	0
P. Rosling	5	5	0
Sir John Snell	5	5	0
L. C. F. Bellamy	5	0	0
J. M. Donaldson	5	0	0
P. Hamilton	5	0	0
J. M. Kennedy	5	0	0
R. G. Kilburne	5	0	0
H. E. Morrow	5	0	0
G. H. Nisbett	5	0	0
K. A. Scott-Moncrieff	5	0	0
R. M. Sethna	5	0	0
E. A. Short	5	0	0
and 3 379 donations of under £5	1 236	14	0
	£1 923	4	4

Legacy

The Fund also benefited to the extent of £50 under the will of the late Mr. J. D. Dallas, who subscribed to the Fund for many years.

Electrical Engineers' Ball

The annual Electrical Engineers' Ball, held on the 5th February, 1937, realized a surplus of £244 4s. 1d., which was handed to the Fund.

Income

The total income from all sources for 1937 was £4 338 9s. 3d., which compares with £4 328 13s. 6d. for 1936.

Grants

Applications for assistance were made by or on behalf of 81 persons during 1937, and the Committee after due consideration made grants in 73 of the cases. In assisting these persons the Fund also provided for the necessities of 69 dependants. In 1936 74 applications were received, and grants were made in 73 cases.

The total amount of the grants was £4 434 3s. 7d., which compares with £3 720 3s. 3d. for 1936.

Donors and Subscribers

Lists of the names of donors and subscribers are issued to members of The Institution annually, and the Committee of Management desire to tender their cordial thanks to all the contributors.

In 1937, for the first time in the history of the Fund, the income from all sources was insufficient to meet the demands, notwithstanding the fact that a number of applicants were not assisted.

This serious position, if maintained, will cause the Committee of Management much anxiety on account of meeting the many claims, and they earnestly appeal to all members of The Institution who are not subscribers to send a donation or annual subscription, so that the present standard of relief may be maintained. At present, only 31 % of members subscribe to the Fund.

Wilde Fund

The Capital Account stood on the 31st December, 1937, at £3 049 16s. 2d., all of which is invested and brings in an annual income of about £104 17s.

The balance standing to the credit of the Income Account (from which, under the Trust Deed, only full Members and their dependants can benefit) on the same date was £22 10s. 3d.

Grants amounting to £104 were made from this Fund during the year.

THE BENEVOLENT FUND OF THE INSTITUTION OF ELECTRICAL ENGINEERS.

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR 1937.

Dr. EXPENDITURE.

Year ended 31 Dec., 1936. £ s. d.		£ s. d.
3,720 3 3	To Grants	4,434 3 7
40 5 7	,, Printing, Stationery, Postages, etc.	31 10 3
(Unexpended Balance) 568 4 8		
£4,328 13 6		£4,465 13 10

INCOME. **Cr.**

Year ended 31 Dec., 1936. £ s. d.		£ s. d.	£ s. d.
1,057 16 1	By Dividends and Interest		1,012 15 10
230 1 5	,, London Electrical Engineers' Ball		244 4 1
	,, Donations of £5 and over:—		
	Mersey and North Wales (Liverpool) Centre Golf Tournament	120 0 0	
	North-Western Centre Golf Tournament	105 0 0	
	Incorporated Municipal Electrical Association, Golf Tournament	21 0 0	
	Scottish Centre Golf Tournament	11 16 6	
	South Midland Electrical Engineers' Ball	65 0 0	
	North-Western Centre, Manchester Engineers' Ball ..	15 15 0	
	Other donations	347 18 10	
840 5 6			686 10 4
1,133 11 0	,, Donations under £5		1,236 14 0
1,066 19 6	,, Annual Subscriptions		1,108 5 0
	,, Legacy from the late Mr. J. D. Dallas		50 0 0
	,, Deficit carried to Balance Sheet		127 4 7
£4,328 13 6			£4,465 13 10

BALANCE SHEET, 31st DECEMBER, 1937.

Dr. LIABILITIES.

		£	s.	d.
To Capital Account:—				
As per last Balance Sheet		23,863	2	2
,, Income and Expenditure Account:—				
As per last Balance Sheet	£3,508 12 2			
Less Deficit in 1937	127 4 7			
		3,381	7	7
,, Grants authorized but not yet disbursed		130	0	0
,, Sundry Creditors		24	12	10
,, Subscriptions and Donations received in advance		5	9	6
,, Overdraft at Bank	27 9 10			
,, *Less* Cash in hand	9 9 5			
		18	0	5
		£27,422	12	6

ASSETS. **Cr.**

		£	s.	d.
By Investments (Capital), at cost:—				
£961 7s. 7d. Cape of Good Hope 3% Stock (1933–43)		950	0	0
£420 London and North Eastern Railway 4% First Preference Stock		503	18	3
£450 London, Midland and Scottish Railway 4% Debenture Stock		551	0	9
£750 East Indian Railway 3½% Debenture Stock		737	18	0
£300 London, Midland and Scottish Railway 4% Guaranteed Stock		333	11	6
£500 New Zealand 3½% Stock (1940)		486	18	6
£500 Canada 3½% Stock (1930–50)		478	16	0
£5,800 3½% War Stock		5,783	6	1
£350 New South Wales 4% Stock (1942–62)		336	18	6
£2,580 4% Funding Stock (1960–90)		2,123	15	6
£3,295 3½% Conversion Stock (1961)		2,512	11	10
£450 Commonwealth of Australia 5% Stock (1945–75)		438	16	0
£450 Tynemouth Corporation 5% Stock (1947–57)		457	7	3
£950 Agricultural Mortgage Corporation 5% Debenture Stock (1959–89)		988	5	6
£1,000 Southern Railway 5% Redeemable Guaranteed Preference Stock (1957)		1,028	7	0
£1,000 Southern Railway 5% Guaranteed Preference Stock		1,000	3	0
£1,000 Hastings Corporation 5% Stock (1947–67)		980	2	0
£800 London Passenger Transport Board 5% "A" Stock (1985–2023)		808	2	6
£700 Ayr County Council 5% Stock (1947–57)		733	7	0
£1,000 Commonwealth of Australia 4% Stock (1955–70)		1,012	13	0
£900 South Essex Waterworks Co. Perpetual Debenture 4% Stock		1,014	4	6
£650 London County Council 2¾% Consolidated Stock (1960–70)		602	19	6
(*Market value 31st December*, 1937, *£26,300 11s. 4d.*)		£23,863	2	2
,, Investments (Income) at cost:—				
£1,050 Newcastle and Gateshead Water Co. 5% Consolidated Preference Stock	£1,513 14 6			
£1,050 London County Council 2¾% Consolidated Stock (1960–70)	977 15 9			
£1,000 3% Funding Stock (1959–69)	1,033 5 6			
(*Market value 31st December*, 1937, *£3,282 5s. 0d.*)		3,524	15	9
,, Sundry Debtors		34	14	7
		£27,422	12	6

I have audited the above Balance Sheet and Income and Expenditure Account with the Books and Vouchers and certify them to be correct, and have verified the Investments with Certificates from Banks.

ARTHUR J. ATTFIELD, A.C.A.,
Honorary Auditor.

27th April, 1938.

INSTITUTION NOTES

INDEX TO JOURNAL

Any member who proposes to bind the current volume of the *Journal* and would like to have an extra copy of the Index, for filing apart from the bound copy of the *Journal*, can obtain an additional copy on application to the Secretary.

THE ENGINEERS' GERMAN CIRCLE

In addition to the meetings mentioned on page 579 of Institution Notes in the October issue (No. 502) of the *Journal*, the following has been arranged:—

Monday, 19th December, at The Institution of Electrical Engineers, at 6 p.m. (Light refreshments at 5.30 p.m.) Lecture on "Current Problems of Television Technique in Germany," by Herr Ministerialrat Gladenbeck, Head of the Research Department of the German Post Office. The proceedings will be in German. The meeting is open to all members of The Institution.

INTERNATIONAL ELECTROTECHNICAL VOCABULARY

The First Edition of the above Vocabulary has now been published by the International Electrotechnical Commission. About 2 000 technical terms are defined in both English and French, and the terms themselves are also translated into German, Italian, Spanish, and Esperanto. The terms are grouped under the following headings: General; Machines and Transformers; Switchgear; Measuring Instruments; Generation, Transmission, and Distribution; Traction; Electro-mechanical Applications; Electric Heating; Lighting; Electro-chemistry; Telegraphy and Telephony; Radio Communication; Radiology; Electro-biology.

Copies of the Vocabulary can be obtained from the British Standards Institution, Publications Department, 28 Victoria Street, London, S.W.1, price 10s. each, or 10s. 6d. post free.

SCHOLARSHIPS

The following Scholarships have been awarded for 1938 by the Council:—

Ferranti Scholarship (*Annual Value* £250; *tenable for* 2 *years*)

L. S. Piggott, M.Sc.(Eng.) (Oxford University).

Duddell Scholarship (*Annual Value* £150; *tenable for* 3 *years*)

J. B. Higham (Penarth County School).

Silvanus Thompson Scholarship (*Annual Value* £100, *plus tuition fees; tenable for* 2 *years*)

H. Darnell (Mersey Railway Company).

Swan Memorial Scholarship (*Annual Value* £120; *tenable for* 1 *year*)

J. G. Hutton, B.Sc. (Sunderland Technical College).

David Hughes Scholarship (*Value* £100; *tenable for* 1 *year*)

H. E. Newton (Sheffield University).

Salomons Scholarship (*Value* £100; *tenable for* 1 *year*)

C. Halliday (King's College, Newcastle-on-Tyne).

Thorrowgood Scholarships (*Annual Value* £12 10*s. each*; *tenable for* 2 *years*)

E. C. Norris (Southern Railway).
C. R. Smith (London and North-Eastern Railway).

WAR THANKSGIVING EDUCATION AND RESEARCH FUND (No. I)

The following grants have been made for 1938–1939 for research purposes:—

£50 to J. W. Carroll (King's College, London).
£25 to E. Franklyn (Birmingham University).
£25 to G. Y. Shute (University College, Nottingham).

INFORMAL MEETINGS

211TH INFORMAL MEETING (14TH FEBRUARY, 1938)

Chairman: Mr. J. R. Jones.

Subject of Discussion: "Electric Radiators of the Heat-Storage Type" (introduced by Mr. W. L. Shand).

Speakers: Messrs. J. I. Bernard, B.Sc.Tech., W. Hawthorne, B.A., B.E., A. G. Kemsley, H. J. Bullard, G. H. Fowler, G. O. McLean, M.Eng., J. Lesser, F. Jervis Smith, F. E. Rowland, W. J. Nicholls, B.Sc., R. G. Case, E. Ackery, H. J. Cash, P. P. Wheelwright, and G. Y. Fraser.

212TH INFORMAL MEETING (28TH FEBRUARY, 1938)

Chairman: Mr. M. Whitgift.

Subject of Discussion: "The Widening Scope of Electrical Meters and Instruments" (introduced by Mr. G. F. Shotter).

Speakers: Messrs. L. M. Smith, E. S. Ritter, E. W. Hill, B. Wood, M.A., F. E. J. Ockenden, F. Jervis Smith, H. G. F. Lambe, E. H. Miller, H. J. Bullard, L. C. Gleaves, W. L. Beck, J. F. Shipley, S. C. Bartholomew, M.B.E., I. O. Hockmeyer, B.Sc.Tech., A. M. Hodgson, A. G. Kemsley, and P. P. Wheelwright.

213TH INFORMAL MEETING (14TH MARCH, 1938)

Chairman: Mr. A. F. Harmer.

Subject of Discussion: "High-Tension Direct Current" (introduced by Mr. J. E. Calverley).

Speakers: Messrs. E. Ambrose, W. Donnelly, B.Sc. Tech., B. Wood, M.A., J. L. North, P. C. Bullock, G. F. Bedford, B.Sc., E. Gallizia, J. C. Read, B.Sc., S. A. Stevens, W. E. Warrilow, J. E. Macfarlane, B.Sc.(Eng.), D. Kerr, J. L. Miller, D.Eng., Ph.D., and A. Williams.

214TH INFORMAL MEETING (28TH MARCH, 1938)

Chairman: Mr. J. F. Shipley.

Subject of Discussion: "Engineering Economics in Planning" (introduced by Mr. F. Gill, O.B.E.).

Speakers: Messrs. J. M. Kennedy, O.B.E., J. G. Hines, Major H. Brown, Messrs. N. C. Rolfe, B.Sc.(Eng.), A. Morgan, W. R. C. Coode-Adams, M.A., M.Sc., Ph.D., D. Gough, L. Meek, A. Rosen, B.Sc.(Eng.), Ph.D., G. O. McLean, M.Eng., S. C. Bartholomew, M.B.E., H. Kingsbury, F. Jervis Smith, G. F. Bedford, B.Sc., and J. F. Shipley.

215TH INFORMAL MEETING (11TH APRIL, 1938)

Chairman: Mr. N. C. Rolfe, B.Sc.(Eng.).

Subject of Discussion: "Air Conditioning" (introduced by Mr. R. J. C. Barrington).

Speakers: Major H. Brown, Messrs. E. Ackery, S. O. Shircore, T. E. Harris, T. C. Angus, W. S. Sholl, A. Morgan, Dr. W. Y. Lee, Messrs. Forbes Jackson, S. C. Bartholomew, M.B.E., B. F. Browne, G. O. McLean, M.Eng., J. F. Shipley, P. C. Bullock, F. Peake Sexton, C. F. Boak, C. Fisher, H. J. Cash, and N. C. Rolfe, B.Sc.(Eng.).

PROCEEDINGS OF THE METER AND INSTRUMENT SECTION

75TH MEETING OF THE METER AND INSTRUMENT SECTION, 4TH FEBRUARY, 1938

Mr. H. Cobden Turner, Chairman of the Section, took the chair at 7 p.m.

The minutes of the meeting held on the 7th January, 1938, were taken as read and were confirmed and signed.

The following papers were read and discussed: "An Objective Noise-Meter for the Measurement of Moderate and Loud, Steady and Impulsive Noises" (see page 249), by Mr. A. H. Davis, D.Sc.; and "The Circuit Noise-Meter (Psophometer) and its Applications" (see page 261), by Mr. H. R. Harbottle, B.Sc.(Eng.), Member. Demonstrations were given in connection with both papers.

A vote of thanks to the authors, moved by the chairman, was carried with acclamation.

76TH MEETING OF THE METER AND INSTRUMENT SECTION, 4TH MARCH, 1938

Mr. B. S. Cohen, O.B.E., Vice-chairman of the Section, took the chair at 7 p.m.

Preceding the meeting a demonstration on "The Determination of Phase-Angle by Cathode-Ray Oscilloscope" (see page 681) was given by Mr. F. de la C. Chard, and the chairman invited remarks on the demonstration.

The minutes of the meeting held on the 4th February, 1938, were taken as read and were confirmed and signed.

The following papers were read and discussed: "The Use of the High-Vacuum Cathode-Ray Tube for Recording High-Speed Transient Phenomena" (see page 657), by Captain D. I. McGillewie, R.N., Associate; and "Recurrent-Surge Oscillographs, and their Application to Short-Time Transient Phenomena" (see page 663), by Mr. K. J. R. Wilkinson, B.Sc., Associate Member. Demonstrations were given in connection with both papers.

A vote of thanks to the authors, moved by the chairman, was carried with acclamation.

77TH MEETING OF THE METER AND INSTRUMENT SECTION, 18TH MARCH, 1938

Mr. G. F. Shotter, Immediate Past-chairman of the Section, took the chair at 7 p.m. in the unavoidable absence of both the Chairman and the Vice-chairman.

The minutes of the meeting held on the 4th March, 1938, were taken as read and were confirmed and signed.

An informal discussion then took place, the subjects being as follows:—

(1) "Meter Practice in Paris" [opened by Mr. A. M. Strickland, B.Sc.(Eng.), Associate Member].

(2) "The Future of Meter Testing" (opened by Mr. O. Howarth, Member).

A vote of thanks, moved by the chairman, to those members who had introduced the subjects for discussion, was carried with acclamation.

78TH MEETING OF THE METER AND INSTRUMENT SECTION, 1ST APRIL, 1938

Mr. H. Cobden Turner, Chairman of the Section, took the chair at 7 p.m.

The minutes of the meeting held on the 18th March, 1938, were taken as read and were confirmed and signed.

The following papers were read and discussed: "Some Polarization Phenomena in Magnetic Materials, with special reference to Nickel-Iron Alloys," by Mr. T. A. Ledward, Associate Member, and "The Use of Auxiliary Current-Transformers for extending the Range of Metering Equipment," by Mr. G. F. Shotter, Member. A demonstration was given in connection with Mr. Ledward's paper.

A vote of thanks to the authors and to Mr. E. W. Hill (who presented Mr. Shotter's paper in the latter's absence through illness) was moved by the chairman and was carried with acclamation.

79TH MEETING OF THE METER AND INSTRUMENT SECTION, 20TH MAY, 1938

Mr. H. Cobden Turner, Chairman of the Section, took the chair at 7 p.m.

The minutes of the meeting held on the 1st April, 1938, were taken as read and were confirmed and signed.

The chairman announced that the following members had been nominated to fill the vacancies which would occur on the Committee on the 30th September, 1938:—

Chairman: B. S. Cohen, O.B.E.

Vice-Chairman: F. E. J. Ockenden.

Ordinary Members of Council: J. L. Ferns, B.Sc., C. W. Hughes, B.Sc., F. J. Lane, M.Sc., and E. H. Miller.

In the event of a ballot for the new Committee being required, Messrs. F. O. Barralet and L. J. Matthews were appointed scrutineers.

The chairman then called upon Prof. A. V. Hill, O.B.E., Sc.D., F.R.S., to deliver his lecture on "Electrical Temperature measurements in Physiology."

A vote of thanks to the lecturer, moved by Mr. B. S. Cohen, and seconded by Mr. F. E. J. Ockenden, was carried with acclamation.

PROCEEDINGS OF THE TRANSMISSION SECTION

24th Meeting of the Transmission Section, 19th January, 1938

Mr. J. L. Eve, Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting held on the 15th December, 1937, were taken as read and were confirmed and signed.

The following papers were read and discussed: "Current Rating and Impedance of Cables in Buildings and Ships" (see page 497), by Messrs. H. C. Booth, E. E. Hutchings, B.Sc.(Eng.), Associate Member, and S. Whitehead, M.A., Ph.D., Associate Member; and "Current Rating of Cables for Transmission and Distribution" (see page 517), by Messrs. S. Whitehead, M.A., Ph.D., and E. E. Hutchings, B.Sc.(Eng.), Associate Members.

A vote of thanks to the authors, moved by the chairman, was carried with acclamation.

25th Meeting of the Transmission Section, 16th February, 1938

Mr. J. L. Eve, Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting held on the 19th January, 1938, were taken as read and were confirmed and signed.

A paper by Messrs. T. W. Ross and C. Ryder, Associate Members, entitled "High-Speed Protection as an Aid to Maintaining Electric Service following System Short-Circuits" (see page 228), was read and discussed.

A vote of thanks to the authors, moved by the chairman, was carried with acclamation.

26th Meeting of the Transmission Section, 9th March, 1938

Mr. J. L. Eve, Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting held on the 16th February, 1938, were taken as read and were confirmed and signed.

Dr. Johannes Adolph delivered a lecture entitled "Recent Aspects of Electricity Distribution in Large Towns" (see page 634).

A vote of thanks to the lecturer, moved by Mr. Johnstone Wright and seconded by Dr. P. Dunsheath, O.B.E., M.A., was carried with acclamation.

A short discussion on the lecture then took place.

27th Meeting of the Transmission Section, 13th April, 1938

Mr. J. L. Eve, Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting held on the 9th March, 1938, were taken as read and were confirmed and signed.

The chairman announced that the following members had been nominated to fill the vacancies which would occur on the Committee on the 30th September, 1938:—

Chairman: S. R. Siviour.

Vice-Chairman: F. W. Purse.

Ordinary Members of Committee: W. M. Booker, J. S. Pickles, B.Sc.Tech., T. R. Scott, B.Sc., and H. Willott Taylor.

In the event of a ballot for the new Committee being required, Messrs. S. C. Bartholomew, M.B.E., and A. M. Perry, B.Sc.(Eng.), were appointed scrutineers.

A paper by Messrs. J. L. Miller, D.Eng., Ph.D., and J. M. Thomson, Ph.D., Associate Member, entitled "The Surge Protection of Power Transformers," was read and discussed.

A vote of thanks to the authors, moved by the chairman, was carried with acclamation.

28th Meeting of the Transmission Section, 11th May, 1938

Mr. S. R. Siviour, Vice-chairman of the Section, took the chair at 6 p.m. in the absence of the Chairman, Mr. J. L. Eve.

The minutes of the meeting held on the 13th April, 1938, were taken as read and were confirmed and signed.

A paper by Mr. H. Purslove Barker entitled "The Centralized Control of Public Lighting and Off-Peak Loads by Superimposed Ripples" (see page 823), was read and discussed.

A vote of thanks to the author, moved by the chairman, was carried with acclamation.

PROCEEDINGS OF THE WIRELESS SECTION

141st Meeting of the Wireless Section, 2nd February, 1938

Mr. W. J. Picken, Vice-chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting held on the 5th January, 1938, were taken as read and were confirmed and signed.

A paper by Prof. C. L. Fortescue, O.B.E., M.A., Member, and Mr. G. Mole, Ph.D., B.Sc., entitled "A Resonance Bridge for Use at Frequencies up to 10 Megacycles per Second" (see vol. 82, page 687), was read and discussed.

A vote of thanks to the authors, moved by the chairman, was carried with acclamation.

142nd Meeting of the Wireless Section, 2nd March, 1938

Mr. T. Wadsworth, M.Sc., Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting held on the 2nd February, 1938, were taken as read and were confirmed and signed.

A paper by Mr. P. P. Eckersley, Member, entitled "A Quantitative Study of Asymmetric-Sideband Broadcasting" (see vol. 83, page 36), was read and discussed.

A vote of thanks to the author, moved by the chairman, was carried with acclamation.

13th Informal Meeting of the Wireless Section, 15th March, 1938

Mr. T. Wadsworth, M.Sc., Chairman of the Section, took the chair at 6.30 p.m.

The minutes of the Informal Meeting held on the 25th January, 1938, were taken as read and were confirmed and signed.

A discussion, opened by Mr. R. C. G. Williams, Ph.D., Graduate, took place on "The Servicing of Broadcast Receivers."

At the conclusion of the discussion a vote of thanks was accorded to Mr. Williams for his introductory remarks.

143RD MEETING OF THE WIRELESS SECTION, 30TH MARCH, 1938

Mr. T. Wadsworth, Chairman of the Section, took the the chair at 6 p.m.

The minutes of the meeting held on the 2nd March, 1938, were taken as read and were confirmed and signed.

A paper by Messrs. J. Bell, B.Sc., J. W. Davies, and B. S. Gossling, M.A., entitled "High-Power Valves: Construction, Testing, and Operation" (see page 176), was read and discussed.

A vote of thanks to the authors, moved by the chairman, was carried with acclamation.

144TH MEETING OF THE WIRELESS SECTION, 6TH APRIL, 1938

Mr. T. Wadsworth, M.Sc., Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting held on the 30th March, 1938, were taken as read and were confirmed and signed.

A paper by Messrs. A. J. Gill, B.Sc.(Eng.), Member, and S. Whitehead, M.A., Ph.D., Associate Member, entitled "Electrical Interference with Radio Reception" (see page 345), was read and discussed.

A vote of thanks to the authors, moved by the chairman, was carried with acclamation.

145TH MEETING OF THE WIRELESS SECTION, 4TH MAY, 1938

Mr. W. J. Picken, Vice-chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting held on the 6th April, 1938, were taken as read and were confirmed and signed.

The chairman announced that the following members had been nominated to fill the vacancies which would occur on the Committee on the 30th September, 1938:—

Chairman: A. J. Gill, B.Sc.(Eng.).

Vice-Chairman: H. Bishop, B.Sc.(Eng.).

Ordinary Members of Committee: A. J. A. Gracie, B.Sc., G. S. C. Lucas, J. S. McPetrie, B.Sc., Ph.D., Col. G. D. Ozanne, M.C., W. J. Picken, and R. T. B. Wynn, M.A.

In the event of a ballot for the new Committee being required, Messrs. F. Jervis Smith and J. P. E. Vigoureux were appointed scrutineers.

Dr. Ralph Bown then delivered a lecture on "Researches in Radiotelephony" (see page 395).

A vote of thanks to the lecturer, proposed by Mr. H. L. Kirke and seconded by Mr. A. J. Gill, was carried with acclamation.

OVERSEAS ACTIVITIES

Argentina

At a meeting held on the 20th May, 1937, Mr. H. C. Siddeley, Chairman of the Local Centre, delivered his Inaugural Address on "Economic and other Conditions of Argentina affecting the Electrical Industry."

Three other papers were read and discussed during 1937. The first, read on the 24th June by Mr. I. C. Grant, Student, was entitled "Some Notes on Design Features governing the Economical Operation of High-Power Broadcast Stations." The second was read by Mr. C. G. Barker, Member, on the 30th September, and dealt with "Telephone Fundamental Planning." The final paper, on "Commercial Condensing Refrigerating Units," was read by Mr. A. P. Gunston, Student, on the 28th October. Though the attendances at the meetings were disappointing, the reading of each of the papers was followed by a good discussion.

On the 23rd May, 1938, Mr. C. G. Barker, Chairman of the Local Centre, delivered his Inaugural Address on "The Benefits of Technical Education." This was followed by a short talk, by Mr. F. Lydall, Member, dealing with the supply industry in Great Britain.

Australia

Queensland.

At a meeting held on the 9th April, 1937, Mr. J. A. Murphy gave an address on "Air Conditioning," illustrated by diagrams and lantern slides.

On the 15th June, 1937, at a meeting of local members of the I.E.E. and members of the Brisbane Division of the Institution of Engineers, Australia, presided over jointly by Mr. J. S. Just and Mr. W. H. R. Nimmo, the following papers dealing with the general subject of "Safety on Roads" were read: "Optical Effects and Reactions," by Dr. E. O. Marks, B.A., B.E.; "Modern Highway Illumination," by Mr. J. C. Saint-Smith, B.E.; "Hazards Inherent in Road Structures," by Mr. K. E. Paterson, B.E.; "Hazards Inherent in Drivers and Vehicles," by Mr. W. A. Rogers.

The following took part in the ensuing discussion: Messrs. D. J. Garland, W. Arundell, W. I. Monkhouse, Sub-Inspector Smith (superintendent of traffic), Dr. R. P. Rheuben, Messrs. A. S. Deacon, E. C. Waldron, A. E. Sharman, L. G. Pardoe, W. H. R. Nimmo, and J. S. Just. A vote of thanks to the authors was carried with acclamation.

Members of The Institution took part, on the 24th June, 1937, in a visit of inspection of the new "Courier-Mail" newspaper offices at Brisbane. After viewing the printing plant and the wireless station on the top of the building the party was entertained to supper by the directors of the newspaper.

On the 30th July, 1937, Mr. L. G. Pardoe, B.Eng., Associate Member, reviewed a paper entitled "Control Rooms and Control Equipment of the Grid System," by Mr. J. D. Peattie, Associate Member (see vol. 81, page 607), and an interesting discussion ensued.

The annual social function was held on the 16th September, 1937, at the Belle Vue Hotel, Brisbane, when the host and hostess were Mr. and Mrs. J. S. Just.

At a meeting held on the 8th April, 1938, Mr. H. Egeberg, B.Sc., Associate Member, presented the paper by Mr. J. S. Pickles, B.Sc.Tech., Member, entitled "Rural Electrification" (see vol. 82, page 333). The chair was taken, in the absence of Mr. J. S. Just, by Mr. W. Arundell, about 40 members and visitors being present.

A discussion introduced by Mr. H. B. Marks, B.E., Graduate, on "Line Protection by Petersen Coils," took place at a meeting held on the 1st July, 1938. Keen interest was shown in the subject, which had special reference to the paper by Messrs. H. Willott Taylor, Associate Member, and P. F. Stritzl, D.Sc.Tech. (see vol. 82, page 387).

Ceylon

On the 30th July, 1937, at Colombo, Mr. D. Lusk, Associate Member, read extracts from the paper on "The Use of Protective Multiple Earthing and Earth-Leakage Circuit-Breakers in Rural Areas," by Mr. H. G. Taylor, M.Sc.(Eng.), Associate Member (see vol. 81, page 761). The following participated in the discussion which ensued: Messrs. H. E. S. de Kretser, L. A. Nagel, A. T. Kingston, M. M. Balasuriyar, B.Sc.(Eng.), J. Wilson, G. E. Misso, P. C. Fernando, Major C. H. Brazel, M.C., and Mr. D. P. Bennett. The meeting concluded with a vote of thanks to Mr. Lusk, which was carried unanimously. Twenty-three members and one visitor were present.

At a meeting arranged by the Local Committee and held at Colombo on the 23rd February, 1938 (Major C. H. Brazel, M.C., in the chair), Mr. S. W. Peiris, B.Sc.(Eng.), Graduate, read a paper entitled "Petersen Coils: a Review of their Application to Overhead Transmission-Line Networks and Cable Systems." In the subsequent discussion the following took part: Messrs. Wijetelika, C. H. J. de Mel, H. Jansen, M. I. Aziez, Major C. H. Brazel, M.C., Messrs. D. P. Bennett, T. S. V. Tillekeratne, and E. C. Fernando, B.Sc.(Eng.).

The 4th Annual General Meeting of the I.E.E. members in Ceylon was held at the Grand Oriental Hotel, Fort, Colombo, on the 2nd April, 1938, Major C. H. Brazel, M.C., in the chair. At the Annual Dinner which followed the Meeting the Chairman delivered an Address dealing with recent electrical developments in Ceylon. Twenty-two members and nine guests were present.

A visit of Students and Graduates of The Institution to Stanley power station, Colombo, led by Major C. H. Brazel, M.C., and Mr. D. P. Bennett (Chairman and Hon. Secretary respectively of the Ceylon Local Committee), took place on the 10th June, 1938. Those present were divided into two groups, each of which was shown round the station by a resident engineer. Tea was then served, and an informal discussion followed. The meeting concluded with a vote of thanks to Mr. G. L. Kirk, of the power station.

On the 1st July, 1938, at a meeting held at Colombo, Mr. S. Rajanayagam, B.Sc., Associate Member, introduced the paper by Messrs. A. J. Gill, B.Sc.(Eng.), Member, and S. Whitehead, M.A., Ph.D., Associate Member, entitled "Electrical Interference with Radio Reception" (see vol. 83, page 345). In the ensuing discussion the levels of interference caused by overhead transmission lines and by private plant such as medical apparatus and welding equipment were compared. The attendance numbered 21, and the following took part in the discussion: Major C. H. Brazel, M.C., and Messrs. G. L. Kirk, D. P. Jayasekera, and L. A. Nagel.

A vote of thanks to Mr. Rajanayagam, proposed by the chairman, was carried unanimously.

China

At a Joint Meeting of the China Centre of the I.E.E., the Engineering Society of China, the Institution of Civil Engineers (Shanghai Association), and the Institution of Mechanical Engineers (China Branch), held on the 6th December, 1937, Mr. S. Flemons (Chairman of the China Centre) in the chair, a paper was read by Mr. C. C. Bojesen, Associate, on "Electrical Safety in Shanghai Factories." Messrs. S. Flemons, J. Haynes Wilson, A. H. Harvey, J. T. Rogers, W. L. E. Miller, W. C. Gomersall, and R. G. Fuller, took part in the subsequent discussion. A vote of thanks to the author, proposed by the Chairman, was carried with acclamation. There was an attendance of 50 members and guests.

On the 7th February, 1938, before a meeting of the China Centre of the I.E.E. and various associated institutions, Mr. W. Miles, Associate Member, presented a paper on "Photo-Electric Cells," and gave a practical demonstration of photo-electric burglar-alarm equipment. The paper was supplemented by a short note contributed by the Chairman, Mr. S. Flemons. The meeting was attended by 51 members and guests, and the following contributed to the discussion: Messrs. N. W. B. Clarke, C. C. Bojesen, W. J. C. Fletcher, A. H. Harvey, W. L. E. Miller, A. B. Whatman, H. G. B. Perry, and P. M. Streit. The meeting concluded with a vote of thanks to the author, proposed by the Chairman.

The subject of "The Development of Radio Direction-Finding," introduced by Mr. W. L. E. Miller, Graduate, was discussed at another Joint Meeting of the same bodies held on the 21st February, 1938, at Shanghai. There was an attendance of 34 members and guests, among whom the following took part in the discussion: Father Gherzi, and Messrs. J. Haynes Wilson, A. B. Whatman, N. W. B. Clarke, N. Maas, and W. J. C. Fletcher. The Chairman brought the meeting to a close by proposing a vote of thanks to the author, which was carried with acclamation.

At the Joint Annual Dinner of the China Centre of the Engineering Society of China and associated institutions, held at the Shanghai Club on the 4th March, 1938, 107 persons were present.

The chair was taken by Mr. C. D. Pearson, Chairman of the Shanghai Association of the Institution of Civil Engineers and of the China Branch of the Institution of Mechanical Engineers. During the evening a presentation on behalf of the three Institutions was made to Mr. Pearson, who was leaving China after over 30 years' service there. The toast of "Our Guests" was proposed by Mr. S. Flemons.

At a further Joint Meeting (presided over by Mr. S. Flemons) held on the 21st March, 1938, of the China Centre of the I.E.E. and the Shanghai members of the other engineering institutions, at which 56 members and guests were present, a paper by Mr. A. B. Whatman, B.A., Associate Member, entitled "The Oxford University Arctic Expedition to North-East Land, 1935–1936" was read, and a general discussion followed. A vote of thanks to the author, proposed by the Chairman, was carried unanimously.

On the 2nd May, 1938, a meeting of the same bodies took place, at which Mr. S. Flemons presided over an attendance of 66 members and guests. A paper was read by Mr. W. Hunter on "Recent Developments in Power Distribution." Messrs. S. Flemons, C. R. Webb, N. L. Anderson, C. H. Mellor, N. Burns, A. H. Harvey, W. L. E. Miller, and Mr. Chow, took part in the subsequent discussion. The meeting terminated with a vote of thanks to the author, proposed by the Chairman and carried unanimously.

India

Bombay.

A social gathering of local members of The Institution was held at Green's Hotel, Bombay, on the 16th November, 1937. This meeting, which marked the opening of the 1937–38 Session, was attended by 46 members and guests.

At a further meeting held on the 19th January, 1938, Mr. E. C. B. Thornton, Associate Member, read a paper on "The Remote Control of Substations." Several members took part in the ensuing discussion. The meeting was attended by 65 members and guests.

Mr. H. G. Taylor's paper on "The Use of Protective Multiple Earthing and Earth-Leakage Circuit-Breakers in Rural Areas" (see vol. 81, page 761) was discussed at a meeting held on the 16th February, 1938, at which 35 members were present.

On the 22nd March, 1938, Mr. K. M. Dordi, B.Sc., Associate Member, presented a paper entitled "The Protective Scheme on the Tata Hydro-Electric Interconnected System." The meeting was attended by 71 members and guests, several of whom took part in the discussion.

A visit to the testing department of the Tata Hydro-Electric Power Supply Co., attended by 24 members of The Institution, took place on the 7th May, 1938. During the visit the party inspected the short-circuit calculating board described in the paper by Mr. K. M. Dordi (see above).

Calcutta.

At a meeting of local members of the I.E.E. held at Calcutta on the 21st January, 1938, Mr. W. C. Ash, B.Sc., read a short paper on "The Civil Engineering Works in connection with the new Mullajore Generating Station." The subject aroused considerable interest among the 36 members and 17 guests who were present.

On the 18th February, 1938, at a meeting arranged by the local Committee, Mr. R. G. Dobeson, B.Sc., Associate Member, introduced the paper on "Safeguards against Interruptions of Supply," by Messrs. H. W. Clothier, Member, B. H. Leeson, Member, and H. Leyburn, B.Sc., Associate Member (see vol. 82, page 445). The attendance numbered 37, and there was a good discussion.

At the concluding meeting of the Session, held on the 18th March, 1938, Mr. W. C. Bartley, Associate Member, read a paper on "Aluminium and its Applications in the Electrical Industry." The attendance numbered 15.

Lahore.

A paper on "Rural Electrification," by Mr. J. S. Pickles, B.Sc.Tech., Member (see vol. 82, page 333), was read on the 3rd March, 1938, at the Maclagan Engineering College, Lahore, at a meeting attended by 48 local members of The Institution. A lively discussion followed the reading of the paper, and the following were among those who took part: Messrs. V. F. Critchley, N. Thornton, G. K. M. Ambady, B.Sc.Tech., T. S. Rao, B.E., and S. P. Ganguly.

On the 26th March, 1938, a party of 30 local members visited the new All-India radio studios in Lahore, and the associated transmitting station on the Amritsar road. The visit proved very successful.

Madras.

At a meeting held on the 11th August, 1937, at Chepauk, Mr. R. M. Steele, Member, showed a cinematograph film dealing with the manufacture of Hewittic rectifiers. This was followed by a meeting on the 18th August, 1937, at which Mr. Steele showed two further films illustrating (1) methods of manufacture and transport of large transformers, and (2) equipment for testing the rupturing capacity of oil circuit-breakers and fuses. There was an attendance of 12 members at each of the meetings.

New Zealand

A dinner for members of the I.E.E., the Institution of Civil Engineers, the Institution of Mechanical Engineers, and the New Zealand Institution of Engineers, was held at the Hotel St. George, Wellington, on the 15th October, 1937. Seventy engineers were present. The toast of "The Chartered Institutions," proposed by His Worship the Mayor of Wellington (Mr. T. C. A. Hislop), was responded to by Mr. J. McDermott (Local Hon. Secretary, New Zealand) on behalf of The Institution of Electrical Engineers.

The paper by Messrs. H. W. Clothier, Member, B. H. Leeson, Member, and H. Leyburn, B.Sc., Associate Member, entitled "Safeguards against Interruptions of Supply" (see vol. 82, page 445), was read by Mr. H. W. Clothier at Dunedin on the 14th January, 1938, at Christchurch on the 18th January, 1938, and at Auckland on the 24th January, 1938. At a meeting held in Wellington on the 31st January, 1938, the same paper was read by Mr. W. A. Simpson, Associate, on behalf of Mr. Clothier, who was unfortunately prevented by illness from attending. The meetings were well supported by members of the I.E.E. and of the New Zealand Institution of Engineers and the New Zealand Supply Authorities Engineers' Association, the attendances ranging from 40 to 70. On each occasion the reading of the paper was followed by a discussion.

South Africa

There was held at Cape Town on the 21st April, 1938, a meeting arranged by the Cape, Natal, and Rhodesia Secretariat of the I.E.E., at which Mr. F. N. Prangnell, Associate, presented a résumé of the paper by Messrs. H. W. Clothier, Member, B. H. Leeson, Member, and H. Leyburn, B.Sc., Associate Member, on "Safeguards against Interruptions of Supply" (see vol. 82, page 445). The résumé was illustrated by lantern slides and a cinematograph film, and was followed by an interesting discussion. The meeting was attended by 28 members and 19 visitors.

MARK ARTHUR BEETLESTONE was born on the 10th October, 1871, and died on the 29th July, 1938. He was educated at Park Walk School, Chelsea, and entered the service of the Post Office as a telegraphist in the Central Telegraph Office in 1886. He obtained his technical education at evening classes at the Northampton Polytechnic, and as a result was appointed a sub-engineer in the Engineering Department of the Post Office in 1900. He was employed for 2 or 3 years on the laying of the original ducts and cables for the "telephoning of London," and later was engaged in telephone and telegraph construction and maintenance, being closely connected with the Central Telegraph Office, and Government and fire brigade installations. In March, 1905, he was promoted to second-class engineer and in July, 1911, to assistant engineer, a position which he held until 1931. He was elected an Associate Member of The Institution in 1921, and a Member in 1925. A. G. L.

JAMES BEVERIDGE ANDERSON BEGG, a partner in the firm of Messrs. Begg and Peebles, consulting engineers, died at Edinburgh on the 29th April, 1938, at the age of 65. He was educated at the Edinburgh Institution, and served a 5 years' apprenticeship with Messrs. James Bertram and Sons, paper-making machinery engineers, Leith. After the completion of his apprenticeship he had a varied experience in engineering and spent some years in South Africa at the diamond mines, where he was responsible for the erection of steam boilers, engines, pumping plant, and pipe lines, and a considerable amount of electrical work. After returning to this country he started business on his own account as a consulting engineer and specialized on the electrical side, including electric lighting and power installations, which he carried through with great success. He was appointed consulting engineer for the Edinburgh Exhibition at Meggetsland, his work including the main power plant for the Exhibition, with steam boilers, engines, dynamos, and the cable lay-out and lighting for the Exhibition buildings and grounds. He was a man with a genial disposition and had many friends, particularly among golfers. He joined The Institution as an Associate Member in 1929, and was elected a Member in 1934.

A. C. P.

RICHARD FRANCIS P. BLENNERHASSETT, who died on the 17th June, 1938, at the age of 58, was educated at Eton and at the Central Technical College, South Kensington. He received his early practical training for a short time with Messrs. Evershed and Vignoles and for 2½ years with the American General Electric Co. at Schenectady. In 1904 he joined the British Thomson-Houston Co. as engineer in their erection department at Rugby. In 1907 he went to the British Aluminium Co. as assistant works manager at Foyers, N.B., and was promoted 2 years later to the position of factory manager at Kinlochleven, where he had charge of the hydro-electric power plant and the aluminium reduction works. From 1914 to 1920 he was an assistant engineer in the employ of Edmundsons Electricity Corporation, except for 2 years during the War when he was an engineer in the Propellant Supplies Department of the Ministry of Munitions. He became chief engineer to Edmundsons in April, 1920, a position which he held until May, 1933, when he was appointed consulting engineer to the company. This post he held up to the time of his death. He was elected a Student of The Institution in 1900, an Associate in 1902, an Associate Member in 1912, and a Member in 1921.

LIEUT.-COL. CHARLES BUTLER CLAY, V.D., born at Liverpool in 1856, was the second son of William Clay, a noted ironmaster of that city. After leaving Malvern College, he served his apprenticeship in mechanical engineering and shipbuilding. In 1881 he entered on his life-work in the public telephone service with the United Telephone Co. in London, subsequently serving with the Northern District and National Telephone Companies for a total of 30 years. After 4 years in London in charge of all the inside apparatus of the company, during which period he took part in their legal defence of its patents, he was moved to the Northern Co. as engineer and manager. Here he quickly showed his quality, for he was one of the earliest engineers to insist upon the use of metallic, instead of earth, circuits; and here also he met and conquered the force of the greatest effort made by the General Post Office in its competition with the telephone companies. In 1893 he was appointed superintendent for all the South of England, except London, and 3 years later he vacated this position and became metropolitan superintendent responsible to the head office for everything in the company's telephone service in the 640 square miles which comprised the London area. He held this office until the end of 1911, when the State took over the service, having participated in the then entire period of telephone development except the first 5 years, and having seen the London service grow from about 1 200 to 220 000 telephones, of which total two-thirds were under his charge, the remaining one-third being on the Post Office system.

Outside of the telephone service he was a keen Volunteer, receiving his first Commission at 18 years of age, and he commanded the 8th Lancashire Artillery Volunteers, in which he served for 23 years. His connection with Volunteers, however, lasted 64 years, for at his death he was a vice-president and a trustee of the National Artillery Volunteer Association. During the Great War he formed and took command of the Engineering Institutions' Volunteer Corps, later called the 1st London Engineer Volunteer Corps. When he retired after 5 years' command he was given the right

to retain his rank of Lieut.-Colonel, Royal Engineer Volunteers, and he had also been given a similar right as Lieut.-Colonel, Royal Artillery Volunteers; this double honour is unique. He had a great sense of the duty of public service; he was a father to all who worked under his direction, and his courage, energy, and ability for prompt action were outstanding features. His kindness was shown by the help he gave to men out of employment and to young men starting to earn their living. He died on the 9th August, 1938. He was elected an Associate of The Institution in 1885 and a Member in 1891. F. G.

HENRY WILLIAM CLOTHIER died on the 11th March, 1938, and his death removed from the electrical engineering profession and industry—particularly the switchgear industry—one whose eminence was universally acknowledged, and whose friendship was profoundly valued by those whose privilege it was to know him well. He was born in London on the 3rd April, 1872, and was educated at St. Mark's College, Chelsea, which he left in 1888. For the next 5 years he served as an apprenticed pupil with Messrs. J. and H. Gwynne, of Hammersmith, and during his apprenticeship he attended evening classes at the Polytechnic and at the City and Guilds Institute. In 1893 he was appointed junior draughtsman and patternmaker with Messrs. Gwynne, and also went for a short visit to the United States. In 1894 he began a period of about 10 years with Messrs. Ferranti, first as designer and draughtsman under the late Dr. S. Z. de Ferranti and Mr. C. P. Sparks in London, and then at Hollinwood in charge of design and contracts for electrical switchgear and transformers. Amongst his many activities he was concerned in the development of the first large oil-break switches put into commercial production in Great Britain, and of the slate-cell switchgear that became very popular about that time.

In 1904 he came to Tyneside—a district that owed much to him in many kindly ways outside his engineering work—to begin, at the suggestion of Mr. C. H. Merz and Mr. Bernard Price, an investigation of protective gear for electrical power generation, transmission, and distribution systems. His attention had been directed for some time to the improvement of high-voltage switchgear, and it was during his investigation that he produced the original designs of the metal-clad draw-out type. In 1906 he joined the staff of Messrs. A. Reyrolle and Co., of Hebburn-on-Tyne, to supervise and direct the developments with which his name, as well as Reyrolle's, will always be linked. His unceasing advocacy of the need for continuity in the supply of electricity and for the safeguarding of human life in its use has borne large fruit, and the whole world has benefited by his work. That, in itself, in his fitting monument; and his influence has been, and will continue to be, felt throughout the electrical engineering industry of every country.

In April, 1937, on reaching the age of 65, he handed over his executive responsibilities to others, though this was far from implying any retirement from general activity—an impossibility for a man of so strong and ardent a nature as his. He continued to have his headquarters at Hebburn, where he was daily available for consultation and advice on all the subjects with which he was profoundly and almost uniquely familiar. On the 29th October, 1937, he sailed for the antipodes, looking forward, as he said, to enjoying three summers in succession; but he became ill while he was in Auckland, N.Z., in the course of the extensive tour he had planned, and an operation was performed in February, 1938. At first all seemed to go well, but complications set in after a fortnight or so, and these eventually proved fatal.

In Institution matters he played a prominent part. He was an Associate Member from 1901 until 1911, when he became a Member; and his work for the North-Eastern Centre, of which he was one of the early members, included a period as Honorary Secretary, and a year as Chairman. He was later an Ordinary Member of Council for 3 years. He gained three Premiums, including the Institution Premium, during his lifetime, for papers read before The Institution, and a Premium was also awarded after his death for a paper of which he was a co-author.

To be associated in any way with him was to have one's education continued and one's outlook enlarged. He was a man of an uprightness and an integrity that brought him the unhesitating trust of his fellows, and his own trust in others was a constant inspiration to high endeavour. Knowing much himself, he was always eager to add to his knowledge by listening to what was said to him and selecting whatever might be worthy for the upbuilding of his own edifice of experience. With his feet planted on solid ground, he kept his gaze ahead, ever on the lookout for the next thing but one, so that he was always calmly prepared for the morrow. He walked firmly through life, and achieved things that will ensure him an enduring place in our annals. T. C.

JOHN RAY COWELL died at Potgietersrust, Transvaal, at the age of 75. Born in Essex, in 1863, he had a colourful career and, as a ship's engineer in his younger days, travelled to many parts of the world. He went to South Africa in the early 'nineties and arrived in Johannesburg in 1894. Establishing himself as a mechanical and electrical engineer, he was appointed, a year later, general manager of the Lighting Department of the Johannesburg municipality, a position which he occupied for 7 years. He resigned that office in 1902 in order to become associated with Messrs. Blane and Co., a well-known firm of engineers in Johannesburg, of which he was managing director until his death. He joined The Institution as a Member in 1898. W. E.-D.

CHARLES WILLIAM SCOTT CRAWLEY, who died on the 9th November, 1937, at the age of 70, was educated at Bonn and at the Hanover-Square School of Electrical Engineering. As a partner in the firm of Nalder, Crawley, and Soames, he invented, designed, and constructed many new instruments and improved the methods of calibrating them. He retired from Nalder Bros. and Co. and set up a well-arranged workshop for electrical and other work at Putney, moving after the War to Charlbury, near Oxford. He joined a Corps of Volunteers and succeeded, although nearly 60, in enlisting in the Anti-Aircraft Force, and was in charge of guns in London and on the East Coast. He helped

in the Automobile Club's motor trials and survey and in designing their first road signs. He assisted the late Dr. George Forbes in the design and construction of range-finders.

He spent much time in the Board of Trade Electrical Standards Laboratory, voluntarily helping Mr. Rennie and working chiefly in the resistance room. Recognizing that the weak point in accurate measurements of resistance had been in the determination of temperature, he considered that high precision might be attained by attention to this, rather than to the low temperature-coefficient of alloys. At his suggestion a thermometer of the highest precision was specially made, and by optical and thermo-electric methods readings were booked to one-thousandth of a degree. He presented to the Board of Trade a "master coil" the temperature-coefficient of which had been measured with great care. He devised the re-arrangement of the resistance room, oil tanks, and thermostats, elaborated the Carey Foster slide-wire bridge until one-fifth of a microhm could be read for ohm comparisons, and devised "built-up" boxes for passing from single ohms to 10 000 ohms, using only two mercury cups at a time.

At the International Conference on Electrical Units and Standards in 1908 he was one of the secretaries, and, as he could converse fluently in French and German, was of great help in explaining matters to the delegates and showing them round the Board of Trade Laboratory. In his workshop at Charlbury he measured the variation of earth currents and constructed an automatic barograph recording rapid variations on a scale 20 times that of a mercury barometer. His accuracy was fastidious, whether he was adjusting a delicate instrument or building a fishing rod.

Owing to his retiring nature his work is not so well known as it deserves. Collaborating with E. C. Rimington he wrote on "The Elements of Electric Light Engineering" in the *Electrician* in 1884, but his name did not appear until the third of the six articles. In 1885 he wrote with F. B. O. Hawes in the same journal on his favourite subject of recording variations of current. When his friends, in later years, urged him to publish something on the work that he loved so well, he said that he could keep his fingers better employed. He joined The Institution as an Associate in 1883, and was elected a Member in 1898. A. P. T.

SIR PHILIP DAWSON, M.P., died in Berlin on the 24th September, 1938, at the age of 71. Born in Paris, he was educated privately, and obtained his theoretical training in electrical engineering at the Belgian Government School of Engineers at Ghent and also at the Montefiore Electrotechnical College attached to the University of Liége. As a young man he travelled extensively on the Continent and in the United States and Canada, making a study of electric traction and power transmission, and on his return to this country he published his impressions in a paper which was read before The Institution in 1894. In 1901 he was appointed consulting engineer to the London, Brighton, and South Coast Railway in connection with their electrification schemes, a position which he continued to occupy for 25 years. From 1901 to 1931 he was a partner in the firm of Kincaid, Waller, Manville, and Dawson, consulting engineers, for whom he carried out important dock, harbour, and electric power and traction schemes throughout the world. His textbook on "Electric Tramways and Railways," published in 1897, was followed in 1909 by two other works—"The Engineering and Electric Traction Pocket Book," and "Electric Traction and Railways." For technical services rendered to the Belgian Government during the War he was created in 1919 a Chevalier de l'Ordre de Léopold. He was also appointed vice-president of the Belgian Royal Commission which inquired into the electrification of the State Railways and the unification of the Belgian electric power supply. He was a member of the Disposals Board of the Ministry of Munitions, and served on the Railway Electrification Advisory Committee of the Ministry of Transport and on the Water Power Resources Committee of the Board of Trade. He was knighted in 1920, and from 1921 until his death was Member of Parliament for West Lewisham. He was a director of Messrs. Johnson and Phillips and of a number of electric supply companies, and was an enthusiastic advocate of a permanent central authority to co-ordinate the power and heating requirements of Great Britain. He was elected an Associate of The Institution in 1891 and a Member in 1896, and for his paper on "Electric Railway Contact Systems," read before The Institution in 1920, he was awarded the Ayrton Premium.

CHARLES FLESCH DE NORDWALL died on the 29th October, 1938, at the age of 88. Educated at the University of Vienna, he was from 1880 to 1887 assistant manager of Messrs. Ganz and Co. In 1888 he went to Australia as a manager of the branch there of the General Electric Co. of New York, and after serving for 5 years in this capacity he was appointed general manager of the foreign department of the Allgemeine Elektrizitäts Gesellschaft. He settled in London about the year 1904, having been made a director of the Allgemeine Elektrizitäts Gesellschaft, managing director of the A.E.G. Electrical Co. of South Africa, and a director of the Electrical Co. During the War he joined the electrical department of Messrs. Vickers, and from 1919 to 1924 was manager of their hydro-electric department. From 1922 until his retirement from active business in 1924 he served on the board of the Metropolitan-Vickers Electrical Export Co. He was elected a Member of The Institution in 1904.

HERBERT HARTLEY DENTON, who died in May, 1938, in his 68th year, was born and educated in Leeds. He served an apprenticeship with Messrs. Fowlers of Leeds, and later, as one of their leading erection engineers, installed generating plant in several of the many power stations which were being built towards the end of the nineteenth century. During this time he also installed generating plant at power stations in Spain, including the important station at Madrid. Having gained this experience he was engaged to reorganize the distribution system at Coventry. Later he took up an appointment as assistant engineer with the Kensington and Knightsbridge Electric Lighting Co. On the 24th September, 1900, he commenced his

life's chief work when he was appointed the first borough electrical engineer of Crewe. From the inauguration of the generating station he proceeded to develop the supply of electricity to all parts of the town, until by the time he retired, in 1935, 75 % of the premises in Crewe were connected to the supply. One of his first efforts was to convert the whole of the street lighting from gas and oil to electric, and later he introduced modern central suspension lighting in the principal streets. Prior to his retirement he realized one of his ambitions by completing a new a.c. distribution system, thus giving the town the full benefit of direct supply by the Central Electricity Board. He was elected an Associate Member of The Institution in 1900, and a Member in 1904. A. D. H.

PERCY REGINALD FRIEDLAENDER died on the 25th March, 1938, at the age of 63. After studying for 2 years at the Finsbury Technical College he entered the works of Messrs. Crompton and Co. at Chelmsford as an improver in 1891, and in 1895 was placed in charge of the design office. He left the firm in 1904 to become a lecturer at the West Ham Municipal Technical Institute, where he was appointed head of the electrical engineering department in 1906, a position which he held until 1918. While at West Ham he carried out testing work for the electric supply department of the Corporation and for various engineering firms. He also served on the Board of Studies in Electrical Engineering of London University. On leaving West Ham he was for a short time with Messrs. Scholey and Co. in their design department, with Messrs. Bray, Markham, and Reiss, of Walthamstow, as assistant manager, and with Messrs. Newton Bros., of Derby, as chief designer. In 1923 he was appointed chief designer to Messrs. W. Mackie and Co., and remained with that firm until his death. He was elected an Associate of The Institution in 1901, an Associate Member in 1907, and a Member in 1912. K. E.

ROBERT LORAINE GAMLEN, O.B.E., born in 1874, was educated at Charterhouse and became a pupil of the late Mr. Hesketh at the Blackpool electricity works. He later joined the British Insulated and Helsby Cable Co., with whom he remained until he transferred to the Edmundson group, by whom he was employed at Forest Gate and Bromley, Kent. At the latter place he was largely responsible for the extension of the original power station and, on the completion of that work, remained in charge of the plant. In 1903 he was appointed general manager of the Lancashire Electric Power Co., constructing their power station at Radcliffe and installing the first 11 000-volt bare overhead power transmission lines in this country. In 1906 he went to India, where he was engaged in cable work for a short period, but was very soon appointed Master of the Mint to the Nizam of Hyderabad. As Master of the Mint he was responsible for all electrical and mechanical engineering work in the State of Hyderabad, and carried out a great deal of experimental work there in connection with an early pulverized-fuel installation. In 1936 he retired and went to live in Cyprus, where he died on the 16th December, 1937. Although most of the electrical men who knew him in the early days had seen little of him in recent years, he will always be remembered by them as a bright and cheery companion and one with whom it was a pleasure to discuss any matter of interest. He joined The Institution as a Student in 1893, and was elected an Associate in 1896, an Associate Member in 1902, and a Member in 1905. P. C. P.

ARTHUR GAVEY, inspecting engineer to the Public Works Department, New Zealand, died at Wellington on the 11th October, 1937. Born in 1875, he was a son of the late Sir John Gavey, at one time engineer-in-chief of the British Post Office. He was educated at private schools and also at University College, Cardiff, where he trained for the Navy as an engineer officer, obtaining a Commission in 1897. From 1891 to 1895 he was apprenticed at the Taff Vale Railway Works, Cardiff. He went to South Africa in 1905 as station engineer with the Johannesburg electricity undertaking, and in 1908 became assistant general manager at Pretoria, where he was responsible for the design and erection of the tramway system. He was subsequently resident engineer to various gold-mining companies in South Africa, and in 1913 went to Chile as chief electrical engineer to the Chile Exploration Co. Returning to England in 1915, he was appointed chief electrical engineer to the Department of Explosives Supply at the Ministry of Munitions, in which capacity he was responsible for the electrical equipment of explosives factories. After the War he set up in practice at Auckland, New Zealand, as a consulting engineer, and later became a district electrical engineer under the Public Works Department. He was appointed inspecting engineer at the head office of the Department in 1925. Elected an Associate Member of The Institution in 1904, he became a Member in 1919.

MAJOR CHARLES BUTLER GRACE, son of the late Dr. W. G. Grace, the famous cricketer, died on the 6th June, 1938, at the age of 56. On leaving Clifton College in 1899 he entered the Crystal Palace School of Practical Engineering, where he devoted himself particularly to the electrical side. In 1902 he became assistant to the clerk of works at the Mansfield Corporation's electricity and destructor plant, which was then in course of erection, and on the completion of the installation early in the following year he entered the employ of the Corporation as a switchboard attendant. He was promoted to charge engineer in 1904, and to senior charge engineer in 1905. Leaving Mansfield in 1907, he was appointed to a position in the electrical engineer's department at Chatham Dockyard, where he was engaged in supervising installation work, including a new system of telephones for the Dockyard. In 1909 he was transferred to the post of station supervisor at the Royal Naval College, Greenwich. In 1914 he joined the Royal Engineers as officer in charge of all machinery and telephones in the Isles of Sheppey and Grain, and the Medway defences. After the War he was made a director of West Kent Works, Ltd., agricultural engineers, Westerham, and in 1923 became engineer and manager of Industrial Silica, Ltd., Wadhurst. From 1925 onwards he was managing engineer of the Weald Electricity

Supply Co. He collapsed and died while playing cricket at Bexhill, Sussex, for that company's club. He joined The Institution as a Student in 1903, was elected an Associate Member in 1908, and became a Member in 1934.

CHARLES C. HAWKINS, C.B.E., M.A., died on the 9th September, 1938, aged 74. He was educated at Eton, where he held a King's Scholarship, after which he proceeded to Magdalen College, Oxford, with a demyship. At Oxford he had a brilliant career, gaining a first class in Honour Moderations, and finally a first class in "Literae Humaniores." After leaving Oxford he decided on an engineering career and studied at the Hanover-Square School of Electrical Engineering. In this entirely new sphere he distinguished himself no less than he had done at Oxford, and on leaving the school he was selected as an assistant by the late Dr. Gisbert Kapp. The design of electrical machinery was then in its infancy, and following on the work of Drs. John and Edward Hopkinson, the relationship between the magnetic and electric circuits of machines was only just becoming subject to exact calculation. For the first time a sure groundwork of theory for the scientific design of dynamos was being laid down, and Kapp, with the assistance of Mr. Hawkins, was eagerly following up and developing the new ideas.

About the year 1890 Mr. Hawkins joined the firm of Messrs. W. H. Allen, Sons and Co. He remained with them for about 20 years as head of their electrical department. During this period he was particularly occupied with the work that most appealed to him, namely the design of electrical machinery. It was his delight to probe ever further into the problems of design that were still awaiting solution. After leaving Messrs. Allen, he was for a time technical editor to a firm of publishers, and in 1912 he joined the Department of Technology of the City and Guilds of London Institute, first as senior officer and then as superintendent of the Department. In this work his previous engineering experience was of great service, as was also his knowledge of the conditions of life in industry, and of the training best adapted to meet them. He retired in 1934, and in recognition of his services the honour of C.B.E. was conferred upon him.

In Mr. Hawkins was combined great technical knowledge and the wide culture that an education in the classics and in the "Greats" School of Oxford represents. He was interested in all human affairs, and on a wide range of subjects he would discourse with much point and humour. With him there was no parade of knowledge, for he was the least pretentious of men, always ready to listen to others and, when the circumstances required it, to talk down to their level. To his friends he was an inspiration, and there are many who know how much they owe to his advice and help. He was extremely fond of music and, though very small of stature, was in his younger days a keen lawn-tennis player and a no-less-keen Alpine climber. His work on "The Dynamo" has become a classic and has run through many editions. He was elected an Associate of The Institution in 1889, and a Member in 1898.

F. W.

CHARLES NELSON HEFFORD, M.Sc., died on the 26th October, 1938, at the age of 63. He was educated at the Leeds Parish Church Middle Class Schools and at Leeds University. On leaving the university in 1896 he was apprenticed for 3 years to Messrs. J. and H. McLaren, with whom he remained until 1904 as head draghtsman, engaged in designing triple-expansion engines for generating stations. He then entered the service of the Leeds Corporation electricity undertaking as chief engineering assistant, and was promoted in 1913 to the position of city electrical engineer and manager of the undertaking, which he held until his death. He was for some years a member of the House and Estates Committee and of the Engineering Advisory Committee of Leeds University, and was until recently on the Technical Consultative Committee of the Central Electricity Board in the Mid-East England Area. Elected an Associate Member of The Institution in 1905, he became a Member in 1926 and served on the Committee of the North Midland Centre from 1926 to 1929, being Vice-chairman in the 1927/8 and 1928/9 sessions.

EDWARD FRIEND HETHERINGTON, whose untimely death on the 22nd July, 1938, at the early age of 51 cut short a promising career, was engineer and manager of the West Midlands Joint Electricity Authority. After spending a year or two with Messrs. Biggs, Wall and Co. he became a substation engineer with the North Metropolitan Electric Power Supply Co. For a short time he was a substation engineer with the Bakerloo Railway, but returned to the power company and served for a time at the Brimsdown power station. He subsequently became assistant to the engineer at the Willesden power station of the company, and eventually succeeded to the position of chief engineer at Willesden. Later he served for a time as assistant to Captain Donaldson, the chief engineer of the company. Early in 1927 he was appointed technical assistant engineer (generation) to Mr. S. T. Allen, then chief engineer and manager of the West Midlands Joint Electricity Authority. When, in 1928, Mr. Allen became the Central England manager of the Central Electricity Board, Hetherington was appointed to succeed him and was responsible for the designs and specifications of the Ironbridge generating station of the Authority and for the extensions now in progress. He was also responsible for the design and carrying out of the scheme of distribution over 600 square miles in the Shropshire area.

In his early years he took a keen interest in the Students' Section of The Institution. He was joint author with R. C. Plowman of a paper read in 1911 on "Exhaust Steam Turbines" which was awarded a Students' Premium and was published in Vol. 47 of the *Journal*. Later he took an active interest in the Informal Meetings and served on the Committee from 1921 to 1924. He interested himself in Local Section affairs, being a member of the Committee of the South Midland Centre from 1930 to 1933 and Vice-chairman for the session 1933–1934. It was at that time his health began to give way and he had to relinquish the position. He made valuable contributions to discussions in both Birmingham and London. He joined The Institution as a Student in 1905, and was elected an

Associate Member in 1912 and a Member in 1924. He was generous, of a cheerful nature, and beloved by his colleagues. E. W. M.

WILLIAM EDEN HIGHFIELD, who died at the age of 58 on the 7th May, 1938, following a major operation in January, was the youngest son of Samuel and Sarah Highfield, of Colwyn Bay. After a mechanical training on leaving school, he joined the Chloride Electrical Storage Co. in 1898 and became an assistant engineer to that firm in 1902. While with the firm, he was engaged in installing reversible boosters, invented by his brother J. S. Highfield, which that firm introduced. This work was his first introduction to the design of direct-current machinery, which later he put to such good purpose. In 1906 he joined Messrs. Dick, Kerr and Co., of Preston, remaining with them until 1920. At Preston, as chief designer of direct-current machinery, his sound knowledge of principles and engineering instinct had wide play. When the War came he was given the task of turning the electrical shops into a factory for the manufacture of shells. This he did with complete success. He was also concerned in the development and production of flying boats. His inventive ability is best shown by the design of the transverter, in conjunction with J. E. Calverley. After long experiment a set rated at 2 000 kW, and designed to operate at 100 000 volts direct current, was made by the English Electric Co. and exhibited at the Wembley Exhibition in 1924. In 1921 he joined his brother, J. S. Highfield, in partnership, and in 1924 they were joined by Roger T. Smith. W. E. Highfield looked on engineering as the art of making things, helped by all that science could bring to assist manufacture.

Apart from his success as a designer and an engineer in the fullest sense of that word, perhaps his outstanding achievement, primarily for The Institution but extending beyond their interests, was his educational work. He was a leading spirit in the establishment and working of the National Certificate in Electrical Engineering, and his grasp of the essentials of technical education was recognized and appreciated by the officials of the Education Department as well as by his colleagues of The Institution.

He was at one time President of the Supervising Electrical Engineers and President of the Batti-Wallah Society, in each case following his brother J. S. Highfield. His interest in things in general was as wide as his reading. He had a very good memory, and his knowledge of world history was extensive. He was an authority on the Napoleonic Wars and on the Roman Empire, but he was equally an authority on paint, cricket, and the virtues of all sorts and conditions of people with whom he came in contact. His nature, simple and affectionate, at once courted acquaintanceship which, in many cases, ripened into friendship. He was a very modest man, and perhaps it was only the solicitude of his friends during his illness which finally convinced him how high he stood in the esteem and regard of acquaintances and the affection of friends. He has been taken at an early age from the home he loved, from the friends whom he cherished, and from the engineering profession that he adorned. He was gifted with wit and humour, which do not often go together, and he met life with an infectious gaiety and its troubles with courage.

He joined The Institution in 1911 as an Associate Member, was elected a Member in 1920, and served as an Ordinary Member of Council in 1924–1927, and as a Vice-President from 1934 to 1937.

R. T. S.

EDMUND LEWIN HILL, who was born at Tottenham, London, in 1871 and who died on the 15th September, 1938, at Melbourne, was the youngest son of the late Dr. George Birkbeck Hill, the famous Johnsonian scholar. He was educated at Haileybury School and at University College School, London. On leaving school he served a pupilage for $2\frac{1}{2}$ years to the locomotive superintendent of the London, Brighton, and South Coast Railway, after which he was appointed an assistant engineer in the firm of Messrs. Urquhart and Bates, in which position he supervised a number of electrical contracts and carried out experimental work. In September, 1891, he founded the firm of Messrs. Hill, Upton, and Co., at Oxford, and carried out a number of installations in the colleges in that city. In 1898 he was appointed by Messrs. C. and A. Musker, of Liverpool, assistant works manager, and he designed, erected, and ran for a short time the power station at Witney. In January, 1902, he was appointed general manager of the South Wales Electrical Power Distribution Co., a position which he held for 4 years. He then joined the firm of Siemens Brothers Dynamo Works, Ltd., as chief assistant in, and later as manager of, the Manchester branch. After 11 years with that firm he became general secretary to the Federation of British Industries. He was responsible for the formation of The Engineers' Club, Manchester, of which he was honorary secretary for many years, and he was also secretary of The Engineers' Club, London, of which he was the founder. He went in 1927 to Melbourne, where he represented the Hackbridge Electric Construction Co., the Hewittic Electric Co., and the Sperry Gyroscope Co. He joined The Institution as an Associate in 1896, and was elected an Associate Member in 1899 and a Member in 1917. His gentle nature and subtle humour endeared him to all.

W. W. H.

TOM HOOD, who died in April, 1938, at the age of 59, was managing director of Messrs. T. Hood and Co., electrical and mechanical engineers, of Clifton. Educated at private schools and at Grimsby Grammar School, he received his theoretical training in electrical engineering at the Municipal Technical School, Hull, and the Goldsmiths' Institute, London. After serving as an apprentice for 5 years with Earles Shipbuilding and Engineering Co., of Hull, he continued for a time with the firm as a draughtsman, and then in 1899 took an appointment as an engineer with the General Steam Navigation Co., Deptford. The following year he joined the engineering staff of Messrs. Witting Brothers and Eborall, London, for whom he supervised the construction of generating plant at Charleroi and elsewhere. From 1904 until his death he was in business on his own account at Bristol as the representative in South-West-

England of a number of electrical manufacturers, and he also acted as consulting engineer to various municipal and industrial undertakings. He was elected an Associate Member of The Institution in 1919, and a Member in 1935. He was a member of the Committee of the Western Centre from 1920 to 1923, and was also for some years a Local Honorary Treasurer, for the Western Centre, of the Benevolent Fund.

SAMUEL INSULL, who died in Paris on the 16th July, 1938, was born in Westminster on the 11th November, 1859, and commenced work as a clerk in the City of London. He became secretary to the London representative of the late Thomas A. Edison, and when the latter visited this country in 1881 he took Insull back to the United States as his secretary. Insull there attended to the administrative side of Edison's work and managed the various companies which were formed to place on the market and develop Edison's numerous inventions. When, in 1892, the various Edison companies were merged with the Thomson-Houston Co. to form the General Electric Co. of America, he became a vice-president in charge of manufacturing and sales. Shortly afterwards he resigned and went to Chicago as president of the Chicago Edison Co. and of the Commonwealth Electric Co., which in 1907 became the Commonwealth Edison Co. The scope of this undertaking was gradually extended until it included practically all the public utility services over a very wide area. Insull was on the boards of these subsidiary companies and chairman of the majority. As a result of the business slump of 1930–31, however, which brought financial disaster to so many companies, he resigned from the management of the companies and came to Europe. He returned to America in 1934, and in 1936 became chairman of a company operating a number of wireless stations in the Middle-West States. He joined The Institution as a Foreign Member in 1894, and was elected a Member in 1911.

ALFRED EDWARD JACKSON died on the 17th December, 1937, at the age of 68. He received his theoretical training at Mason Science College (now the Birmingham University), and was subsequently a pupil with the Gülcher Electric Light and Power Co. In 1891 he became an assistant engineer with the same company, resigning in 1893 to join the Brush Electrical Engineering Co. as a draughtsman on work connected with the design of plant for central stations. His next position, which he filled from 1896 to 1897, was that of estimating engineer with Messrs. Johnson and Phillips. From 1897 until his death he was associated with the firm of Kincaid, Waller, Manville, and Dawson, consulting engineers, first as principal assistant engineer and later as one of the partners. His work for the firm included the preparation of designs and specifications for many large electric traction, power, and lighting undertakings, and the supervision of the erection and testing of the plant. The partnership between him, Sir Edward Manville, Sir Philip Dawson, and Mr. H. G. Simmonds, was dissolved in 1931, the firm continuing under the same name with Mr. Jackson at its head. He was elected an Associate of The Institution in 1895, an Associate Member in 1902, and a Member in 1904.

ALBERT WILSON JONES, who died on the 11th December, 1937, at the age of 70, received his technical training at the West London College of Electrical Engineering and with the Taunton Electric Lighting Co., first as pupil and then as assistant engineer. From April, 1889, to November, 1890, he was chief engineer to the Exeter Electric Lighting Co., leaving to take charge of the City office of the Laing Wharton Down Construction Syndicate, a position which he held for 4 years. In 1894 the name of the company was changed to the British Thomson-Houston Co. and Mr. Jones was appointed head of the London drawing office and estimating department, subsequently becoming in 1900 assistant manager. Altogether he served for 47 years with the company at their London office. During that period, among the electrification schemes on which he was engaged were those of the Central London Railway, the Waterloo and City Railway, the Great Northern and City Railway, the London United Tramways, and the tramways at Bristol, Glasgow, Dublin, Sheffield, Isle of Thanet, Lanarkshire, Chatham, Paisley, and Cork, also the electric lighting of Croydon, Cork, and the Isle of Thanet, among many other lighting installations. He joined The Institution as an Associate in 1890, and was elected a Member in 1903. A. C.

JAMES JOHN LOFTUS was born in London on the 13th February, 1885, and was educated at St. Mark's School, Kensington, at the Regent Street Polytechnic, and at Finsbury Technical College. He received his practical training from 1899 to 1902 with Messrs. Strade and Co., and subsequently, for short periods, with the St. Pancras and Woolwich Electricity Departments. In 1903 he was appointed a shift engineer at Aldershot, being promoted in 1913 to the position of chief assistant engineer. From May, 1922, until January, 1930, he held the position of deputy chief electrical engineer, Southern Command, and from January, 1930, until January, 1931, was deputy chief electrical engineer, Aldershot Command. He subsequently became chief electrical engineer, Southern Command, and in March, 1935, returned to Aldershot as chief electrical engineer, a position which he held until his death, which occurred on the 26th August, 1938. During the Great War he served with the Royal Engineers and went to Russia with General Ironside's Expedition to Archangel. He was elected an Associate Member of The Institution in 1933 and a Member in 1938. W. H. N.

GUSTAF CHARLES LUNDBERG was born in 1867 and was educated at the Haberdashers' Co.'s Schools and at Finsbury Technical College. He was apprenticed in 1882 to his father, the founder of the firm of Messrs. A. P. Lundberg and Sons. From 1888 to 1891 he was engaged on electric traction work in the United States, first with the Bentley Knight Electric Railway Co. and subsequently with the Thomson-Houston Co. On returning to England he rejoined his father's firm and eventually became joint managing director with his brother, Mr. P. A. Lundberg. He retired from business

a few years ago and died on the 21st April, 1938. He was joint author with the late Mr. W. P. Maycock of "Lektrik Lighting Connectors." He was elected an Associate of The Institution in 1894, an Associate Member in 1899, and a Member in 1906.

ALBERT WATERLOW MAKOVSKI was born at Redhill in 1873, and was educated at Marlborough and at King's College, London. He then obtained experience in cable-laying with the County of London and Brush Co. In 1896 he founded with Mr. Struan Tamplin the firm of Messrs. Tamplin and Makovski, at Redhill. In 1907 the business was transferred to Reigate, where it is still carried on. One of his earliest contracts was the installation in 1898–1899 of up-to-date stage lighting at the Royal Opera House, Covent Garden, under the direction of Mr. Wingfield Bowles, the consulting engineer. He joined The Institution as an Associate in 1896, and was elected an Associate Member in 1901 and a Member in 1927. He was also a founder-member of the Electrical Contractors' Association.

BERNARD ALFRED MARTIN-COOPER was born on the 8th April, 1888, and died on the 25th November, 1937. He was educated at Hailey School, Bournemouth, at Eastbourne Public School, and at Bournemouth Technical College, and obtained his theoretical training in electrical and mechanical engineering at the City and Guilds (Engineering) College, South Kensington. After practical training with the Bournemouth Corporation Tramways Department, and the Bournemouth and Poole Electric Supply Co., he was appointed in 1908 a mains maintenance assistant in the testing department of the Newcastle-on-Tyne Electric Supply Co. He left the company in 1912 to become mains and substations superintendent with the Blackburn Corporation Electricity Department, where he was responsible for the construction, operation, and maintenance of static substations. Resigning this appointment in 1918, he went to Dewsbury as mains construction engineer to the Yorkshire Electric Power Co. From 1921 to 1922 he was working on his own account as an electrical and mechanical engineer, carrying out high-voltage tests for the South Wales Electric Power Distribution Co. He then spent a year in London as an assistant in the contracts department of Messrs. Johnson and Phillips. Returning to the Blackburn undertaking as mains superintendent in 1923, he was responsible for the negotiations and other work in connection with the transmission, distribution, and sale of electrical energy throughout the area of supply. In 1931 he resigned from this position on being appointed an electrical inspector of factories under the Home Office. He was elected a Student of The Institution in 1907, an Associate Member in 1912, and a Member in 1927.

WILLIAM MORRIS MORDEY died on the 1st July, 1938, and his name will go down as that of one of the pioneers of electrical engineering during the great development between 1880 and the end of last century. This development was most rapid in the first of these decades.

Born in 1856, he was a North country man, his parents being Durham people. He began electric work very early, going into the Postal Telegraph service at the age of 14. He was soon able to lecture on telegraphy and its scientific principles. In 1881 he joined the Brush Co., which then had its works in Belvedere-road, Lambeth, as head of the testing department. At that time they made dynamos and incandescent lamps, and imported Brush arc lamps and high-pressure 10-ampere arc-lighters from the parent Brush Co. in Cleveland. Mordey was soon promoted to the important position of technical manager, and became responsible for the design of the company's electrical machinery. In the early 'eighties electrical plant in ordinary use consisted of arc-lighters such as the Gramme, Brush, Jablochkoff, and Siemens machines. Of these the last two, and one type of Gramme, were alternators, and they were all of designs that now seem very quaint. The theory of the magnetic circuit as applied to dynamo design was not understood until Rowland, in a sketchy way, and then Hopkinson, in a complete way, made it clear. During the early part of the decade development went by groping experiment. Mordey tackled the Schuckert dynamo of that time first. This was a direct-current machine, giving about 60 volts for an arc lamp. The armature was a flat ring of iron wire wound all over, and gripped between clamps with padding. He converted it into a strongly-made 4-pole machine, and sent the type out shunt-wound—and compound-wound as soon as compound winding became generally known.

When the industry turned its attention, about 1885, seriously to alternating-current distribution and Westinghouse alternators with smooth wound drum armatures were coming into use, and the Ferranti machine was developed, Mordey evolved a type that was quite new. The Ferranti alternator came out about 1884. This was on the lines of the Siemens alternator, but its armature was a zig-zag of strip copper, instead of thick coils of wire; and, like the Siemens machine, it had as many pairs of opposite poles as equivalent armature coils. Mordey also constructed his armature of strip, but it was stationary, and therefore more easily made robust, while each coil was removable independently. But he used only half as many pole-pieces on a rotating magnet, and excited them all by one coil.

It was generally believed that alternators could not be run in parallel. The Westinghouse plants, for example, had a separate circuit for each machine. Hopkinson had written a mathematical paper in which he had assumed that alternators behaved as self-inductions with electromotive force impressed sinoidally, but this led to nothing. Mordey boldly put two of his machines in parallel and proved they worked perfectly.

It was also believed universally that, though a direct-current dynamo could be run as a motor, it worked badly, because the proper designs of dynamos and motors were radically different. The theory was that a motor should have small field magnets and a large armature, while a generator should have large fields and a small armature. Mordey wrote a paper in the *Philosophical Magazine* in which he exploded this theory. To the engineer of to-day such questions seem absurd, but it was only a few years earlier that Maxwell said one of the great discoveries of the day was the reversibility

of the Gramme machine; and power was transmitted from Creil to Paris to astonish the world. Mordey designed a practical commercial transformer. This led him to go into the question of the ageing of the laminated iron used. He investigated that question, and the best way of insulating the plates.

He eventually left the Brush Co., and started the consulting practice of Mordey and Dawbarn. The partners did a good deal of important consulting work, especially in South America and South Africa. Mordey got paper-makers out of a difficulty. The paper came off the hot rollers strongly charged, and gave trouble. Mordey arranged a special device which discharged the paper as it ran through.

Perhaps the most important of his inventions was a method of concentrating ores. He arranged for the ground ore in a fairly thin layer to pass along a way, the bottom of which rested on a series of magnet poles fed from a 3-phase supply. In old days people talked of a rotary field. Mordey arranged for a field moving continuously across the stream of ore. This has a marvellous effect in separating anything magnetic, or metallic, or having any magnetic hysteresis; so that at the end of the way the ore is divided into two streams. He discovered many curious results in connection with his experiments. The main value of this invention has not been, and is not yet, recognized or appreciated by metallurgists.

He was a very active and valuable member of The Institution, of which he was elected an Associate in 1883, and a Member in 1889. He served as an Ordinary Member of Council for many years, also as a Vice-President from 1904 to 1907, and as President in 1908–9. In 1932 he was elected an Honorary Member of The Institution. He read several important papers, and added a great deal of knowledge during discussions. We have him largely to thank for our building; it was greatly through his influence when he was President that the step of acquiring our present abode was taken, and it has proved a very wise step. He was also very active in urging the purchase of the late Prof. Silvanus Thompson's library by The Institution

In private life Mordey was a staunch friend to those he liked, and often very kind and helpful where help was needed. He was sociable, and was a lively member of the Dynamicables and of the Electroharmonic Society of old days. He used to sing, and was a member of the Bach Choir. He was a great walker, and used to spend his holidays in Switzerland, climbing, and he was a member of the Alpine Club. Before motor cars altered the conditions he was also a keen cyclist; and in later years he used to go long tramps of 20 miles or so on Sundays. J. S.

GILBERT SCOTT RAM, O.B.E., died at Bournemouth on the 21st May, 1938. His death has removed one of the pioneers of the electrical world, but his name will live in association with the code of Home Office Regulations which, issued in 1908, remain unaltered to this day. No greater tribute can be paid than to record that these Regulations, written so long ago, should still be current and effective in a rapidly changing industry. Brief, and conceived in general terms, the code, no doubt, owed much of its success to the masterly memorandum which he wrote by way of explanation and which is properly regarded in the industry as a safety textbook.

In 1882 he was one of the first batch of students at the Hammond Electrical Engineering College, which later became Faraday House, and afterwards he was with Goolden and Trotter under Mr. Sydney Evershed. Having spent 2 years in New York with an electric lamp and instrument-making company, he rejoined the staff of Mr. Robert Hammond and represented him in the inauguration of electricity supplies at Leeds, Blackpool, and Coventry, of which last-mentioned city he became electrical engineer. In this capacity he was responsible for the layout of the Sandy Lane generating station. He was next associated with the Nernst Electric Light Co. Owing to restrictions imposed by the original patents the company was debarred from manufacturing the filaments in England and Mr. Ram, with Mr. Maurice Solomon, set up a small factory in Guernsey for this purpose. Before a market could be cultivated for the lamps, however, the Nernst principle was superseded by the tantalum filament lamp and the company was wound up.

It is, however, as first Electrical Inspector of Factories for the Home Office, to which he was appointed in 1902, that Scott Ram will best be remembered. Invested with authority where previously there had been none in a growing but still delicate industry, his position demanded unusual qualities of tact and technical aptitude, and he proved himself to be prominently fitted for a task where persuasion counts for more than law, and constructive suggestion appeals above official authority. He was always welcomed, even where his visits proved expensive, and by personal influence he created a tradition in the industry and in the service that will long be remembered. For 19 years he acted as Electrical Inspector without qualified assistance, but shortly after the War the growth of the industry necessitated the appointment of additional electrical inspectors.

Among his technical achievements it is evident, from the prominence given in the Regulations to switchboard construction, that he was one of the first to recognize the dangers attending the operation of high-voltage switchboards. Preoccupation with such matters did not, however, blind him to less-spectacular subjects, and his work on the Fittings and Accessories Sub-Committee of The Institution demonstrated the importance he attached to sound design of small apparatus and left its mark on a wide range of products. He retired in 1930, but his interest in many electrical activities was continued and for a time he was president of the Association of Supervising Electrical Engineers. He was elected an Associate of The Institution in 1887 and a Member in 1897. H. W. S.

HENRY AUGUSTUS RATCLIFF was born at Nottingham on the 8th June, 1877, and died on the 26th April, 1938. After receiving a private education, he entered the engineering department of University College, Nottingham, where he took the full 3-year course, which was followed by a further 12 months' research work, principally in connection with the

generation, transmission, and other properties of high-frequency currents. In 1897 he joined the staff of the Manchester Corporation Electricity Department as a meter tester. After holding a number of junior positions on the staff, he was largely instrumental in 1901 in initiating and developing the Polygon Testing Department at Ardwick, Manchester, which, under his direction as executive head, grew into one of the most extensive and up-to-date electrotechnical centres in this country, and was a recognized independent testing station. Here he carried out much valuable pioneer work in connection with many problems associated with the control, transmission, distribution, and application of electricity. Reference should also be made to the original work he did in connection with the street lighting of Manchester. In 1919 he became chief electrotechnical engineer, and in 1925 deputy chief engineer. He resigned from the last-named position in 1927 to become chief electrical engineer to the London Power Co. under his former chief. In this position he was in large measure responsible for the design and layout of switchgear at all the principal power stations and distributing stations of the company, together with the installation of the main transmission and distribution systems. In general, he acted in matters electrical in an advisory capacity to all sections of the company.

He was elected an Associate Member of The Institution in 1902 and a Member in 1911. At the date of his retirement from Manchester in 1927 he was Chairman-Elect of the North-Western Centre. He served on the Council of The Institution for a number of years, and to the work of its Committees he devoted a very great amount of his private time. As author or part-author he also contributed several papers to the *I.E.E. Journal* and also to the I.M.E.A.

He was a man of a modest and very retiring disposition. No one, however, who came into contact with him could fail to be impressed by his immense abilities. Anything that savoured of self-advertisement was abhorrent to him—hence he would rarely allude to his own valuable work or the contribution he himself had made to electrical progress. Whilst appreciating the opposite point of view, he was fearless in expressing his own opinions, and he possessed the soundest of judgment. Careful and exacting to a degree, he would never allow himself to be hustled, and would always take his own time over any work entrusted to him; but, when once his opinion had been given or his report completed, there was usually little or nothing to be added to the conclusions which he had reached.

Apart from his work and his home, he appeared to have few interests in life. It is probably true to say that his circle of friends was limited, and few of these succeeded in really getting to know the man. But in the opinion of one who was privileged to be associated with him over a period of well-nigh 40 years, and who enjoyed his loyal co-operation at all times, there can be little doubt that the electrical industry is the poorer for his passing. S. L. P.

COLONEL FREDERICK WILLIAM ROBERTSON, O.B.E., R.E., who died on the 12th June, 1938, at the age of 62, was educated at Harrow and at the Royal Military Academy, Woolwich. He studied electricity at the School of Military Engineering, where he also obtained a good grounding in general engineering work, including mining and bridge building. In 1897 he became a subaltern in the 4th Submarine Mining Company, Royal Engineers, stationed at Portsmouth Harbour. He went out to Mauritius in 1899 to take charge of all the electric lighting, submarine mining, and electrical communication equipment in the island. Returning to England in 1902, he was appointed assistant instructor in submarine mining and electric lighting at Plymouth, where he remained until his promotion in 1906 to the command of the 35th Electric Light Company, Royal Engineers, at Pembroke Dock. A few months later he was transferred to the R.E. Headquarters, South African Command, as inspector in charge of all the Army electric light, telegraph, and telephone plant in South Africa. From 1912 onwards he was at the War Office as assistant inspector, inspector, and in 1916 chief inspector, of R.E. Stores. During the War he was responsible for the organization of the War Department experimental wireless telegraph section and of the factories making wireless telegraph and telephone instruments for the Department. He was also for some years the War Department representative on the Electrical Sectional Committee of the British Engineering Standards Association. In 1920 he became deputy director of works, Mesopotamia Expeditionary Force, and from 1921 to 1922 he held in addition the post of deputy director of works, Iraq. In 1925 he was promoted to deputy engineer-in-chief, India. He was elected a Member of The Institution in 1919.

WILLIAM HARDING SCOTT, O.B.E., founder of the firm of Messrs. Laurence, Scott, and Co. (now Messrs. Laurence, Scott, and Electromotors), died on the 4th September, 1938, in his 77th year. He began his training with the old Hammond Company, and went to Norwich to install electric light at Colman's works, remaining in the city to found the firm of Messrs. Paris and Scott in 1883. He soon gained a reputation for reliable dynamos and motors, being a pioneer of the slotted armature and the inventor of the wave winding, and among the first to use carbon brushes and multipolar machines. Very soon his company began to give a supply of electricity to Norwich, and he introduced a two-rate system of charging (known as the "Norwich" system) for which he designed and made two-rate meters controlled by pilot wires from the power station, and he devised and patented an underground duct system with bare copper conductors. Scott dynamos soon won fame for shipboard use, and finding that slate was unable to stand up to marine conditions, he is said to have invented (and was certainly one of the first to use) the metal-mica principle of insulation for switch and control gear. He also invented and patented a number of mechanisms and systems connected with d.c. control gear. He was the pioneer of the marine electric motor and generator, designing machines specifically for such service. His "Norwich shiplighter" (a high-speed engine set) was typical of his methods, for not content with designing the dynamo he designed the engine too. This was the first example of the high-

speed steam engine for electric lighting sets, prior even to the Willans engine. He invented the electric cargo winch, and before electrical engineering at the Admiralty was raised to the dignity of a directorate he was for many years a sort of unofficial consulting engineer to the Admiralty engineering department. On the purely industrial side he developed motors and control gear for cranes and lifts, printing presses, and other applications needing special designs and individual drive.

During the War he found time, in addition to supervising the manufacture of a great quantity of marine and industrial motors and such equipment as searchlights and winches for kite balloons, to join the Management Committee of the East Anglian Munitions Board. After the War, his sound engineering judgment and fertile brain were applied to improving the designs of younger engineers who were developing the firm's range of a.c. machines, and he had an almost uncanny knack of detecting any errors in design merely by an examination of drawings. Lately he had taken a less active part in the direction of the company, but he continued to take a keen interest in the business and was a regular visitor to the works whenever his health permitted. No words can adequately describe the love and esteem in which he was held by those fortunate enough to work with and under him, his sage advice and inspiration being at the disposal of all. He joined The Institution as a Member in 1904. T. J. B.

JOHN SEVERS was educated at Bingley Grammar School and at Bradford Technical College, and from 1886 to 1891 was apprenticed to Messrs. Thwaites Brothers, engine builders and mechanical engineers, of Bradford. From 1891 to 1894 he was a student at the Central Technical College, South Kensington, where in 1895 he was appointed a demonstrator under the late Prof. Ayrton. Resigning at the end of 1897, he joined the Electric Traction Co. as chief assistant electrical engineer in charge of the construction and first year's running of the Central London Railway. In 1902 he was engaged by Messrs. S. Pearson and Son as chief assistant engineer responsible for the construction and equipment of the Great Northern and City Railway, and on the completion of the work in 1904 he became chief of the engineering staff responsible for the running of the railway. He resigned this position in 1913 on being appointed an assistant to the chief mechanical engineer at the Royal Arsenal, Woolwich, where he was placed in charge of all the electrical work of the department. Later he became assistant superintendent of the department. During his career at Woolwich the electrical system developed from a comparatively small installation to one of the largest industrial systems in the country. In his later years he was responsible for the modernization of the power station and installed up-to-date turbo-alternator and boiler plant. He retired in 1933 and died on the 23rd June, 1938, at the age of 69. His death meant to his late colleagues much more than the loss of his experience and advice, for he had in an exceptional degree a gift of kindliness which endeared him to the hearts of all. He was elected an Associate Member of The Institution in 1901, and a Member in 1913. T. E. H.

SIR JOHN FRANCIS CLEVERTON SNELL, G.B.E., President of The Institution in 1914–1915, was born at Saltash on the 15th December, 1869, and died in London on the 6th July, 1938, at the age of 68. His father was a naval officer, and it had been intended that young Snell should follow the same profession. Difficulties with his eyesight, however, prevented that course from being followed. He was educated at Plymouth Grammar School, and afterwards at King's College, London. After some time with Messrs. Woodhouse and Rawson and Messrs. Crompton and Co., he was appointed assistant to the late General Webber, a Past-President of The Institution. In 1893 he entered municipal service as chief assistant engineer at the Regent's Park power station of the (then) St. Pancras Vestry. A year later he was appointed resident engineer at the King's Road station of the same authority. He remained at St. Pancras until 1896, when he was appointed borough electrical engineer to the Sunderland Corporation. Three years later he was given the additional duties of tramways engineer. In 1896 the Municipal Electrical Association (now Incorporated) was formed and in 1902 he was unanimously elected President. The annual convention, held in Sunderland in July, 1903, under his presidency, was one of the most successful among the early meetings of that body.

In 1906 he made a momentous decision, which was to resign from municipal service and to start in practice as a consulting engineer. He had been considering this step for some time, and originally had the idea of opening an office in Newcastle. He decided, however, to move to London, where he entered into partnership, in Westminster, with Mr. S. S. Moore-Ede. At that time the question of a bulk electricity-supply for London was exciting much interest. In 1905 Mr. Merz had promoted the Administrative County of London and District Electric Power Bill. With a little more luck that Bill would have become law, and the future history of electricity supply in London would have been materially different. The Bill, however, did not pass, but its revolutionary proposals opened the eyes of the various authorities to the possibilities. As a result, other people were soon in the field with counter proposals. Amongst them was the London County Council, which body promoted a Bill in 1906, with the object of becoming the bulk-supply authority for London and district. When the question of giving evidence in favour of that Bill was under consideration, it was decided that the Council's officials should be supported by outside experts. Sir William Preece, Mr. Robert Hammond, and Mr. Snell, were subsequently retained. The fate of the L.C.C. Bill need not be considered here. So far as Mr. Snell was concerned, however, the association with Sir William Preece resulted in an invitation, at a later date, to join the firm of Preece and Cardew. He became a partner in 1910, and the firm then became known as Preece, Cardew, and Snell.

His qualifications as an expert witness were soon recognized, and he appeared in a number of Parliamentary and arbitration cases, principally on behalf of municipal authorities. He was particularly good in rating and valuation cases. He was responsible for work at Bahia Blanca and Bishop's Stortford, and

was engaged on the design of the Harbour power station, Belfast, at the time of his retirement in 1918. His principal case was, undoubtedly, as a witness on behalf of the Post Office, in the arbitration case with the National Telephone Co. in 1912. The Company claimed a sum of £20 924 700 for handing over the telephone system to the Government. Primarily as the result of Mr. Snell's evidence, the award reduced the payment by £8 409 436. Two years afterwards his services were recognized by the conferment of a knighthood upon him.

During the Great War he served on many important Committees, and particularly on the Munitions Inventions Committee. In 1918 he gave up his partnership with his firm (then Preece, Cardew, Snell, and Rider) to advise the Government on electricity matters. He was appointed one of the members of a committee set up to report on the hydro-electric resources of the country; but his chief work, and one with which his name will always be connected, was in connection with the drafting of the Electric (Supply) Bill of 1919. This Bill was passed in December, 1919, and established the Electricity Commission, of which Sir John was appointed chairman. He held this post until January, 1938, when he retired after 19 years' public service, and after some 50 years spent in and for the electrical industry.

During his term as chairman of the Electricity Commission the whole conditions of electricity supply in Great Britain were revolutionized. The Central Electricity Board was formed, the "grid" system was established, and generation and transmission were brought to something approaching standard conditions. It was soon realized that distribution was of equal importance to generation and transmission. Among his last work Sir John was engaged on a scheme for standardizing and combining distribution areas throughout the country. The Bill for carrying this scheme into effect is still under the consideration of the Government.

Sir John held many offices during his career. His Presidencies of The Institution and of the I.M.E.A. have already been mentioned. He was a vice-president of The Institution of Civil Engineers for several years, and, in due course, would have been elected President. For reasons of health, however, he had to decline that honour. He was Chairman of the Engineering Section of the British Association in 1926. He joined The Institution as an Associate in 1891, and was elected a Member in 1896. He served on the Committee of the Newcastle Local Section for many years, also as an Ordinary Member of Council from 1908 to 1911, and as Vice-President in 1911–1914, being elected President in the last-mentioned year. In 1936 he was elected an Honorary Member, and in 1938 he was awarded the Faraday Medal of The Institution.

He liked a quiet home life, and took no part in active sports. He was very fond of music, and, when he lived at Byfleet, had a two-manual pipe organ, on which he frequently played. He took a keen interest in geology, and was a great lover of birds and animals. Sir John was truly a man of many parts, and his recent death, following an operation, so soon after his retirement from public service, came as a great shock to all who knew him.

J. H. R.

JOHN EDWIN STEWART died on the 13th January, 1938, at the age of 72. He received his training in electrical engineering at the Finsbury Technical College, and served with the Edison Co., London, from 1880 to 1882. He then joined Messrs. Woodhouse and Rawson, in whose employ he carried out a number of lighting and tramway installations, including that at the Newcastle Exhibition in 1887. Later he was appointed assistant chief engineer to the General Power and Traction Co., London, and in 1891 was engaged by Messrs. Bramwell and Harris, of Westminster, as an assistant engineer. He was sent by his firm to Derby as resident engineer during the construction of the generating station, and in 1893 was appointed by the Corporation in the same capacity, to become engineer and manager of the undertaking in 1895. Three years later he resigned this position to become resident engineer for Messrs. Kincaid, Waller, and Manville, on work for the St. Lawrence Construction Co. at Messeni, U.S.A. He went next to South America, where he carried out constructional work for the Anglo-Argentine Tramways Co., the La Plata Tramways, and the Buenos Aires Electric Tramways. Elected an Associate of The Institution in 1891, he became a Member in 1898.

HENRY WILLIAM TAYLOR, chief of the turbo-generator engineering department of the British Thomson-Houston Co. at Rugby, died on the 1st February, 1938. Born in London in November, 1884, he joined the staff of the B.T.H. Co. as a junior engineer in September, 1906, having been during the previous 4 years technical assistant to the late Prof. Silvanus Thompson at Finsbury Technical College. With the growth of the company's turbine business a special department was formed to deal with engineering problems connected with turbine-driven generators, and Mr. Taylor was chief assistant in that department under Mr. F. H. Clough, whom he succeeded as head of the department in 1920.

He was a man of considerable mathematical ability and scientific attainments and read several papers before scientific bodies, notably one on "Eddy Currents in Stator Windings" before The Institution in 1919. His paper on "Voltage Control of Large Alternators" was read before The Institution in 1929; and his paper (jointly with Mr. R. T. Coe) on "Some Problems in Electrical Machinery involving Elliptic Functions" was published in the *Philosophical Magazine* in July, 1928. His paper on "The Mechanical Design of Rotating Machinery," written for the Congrès International d'Électricité, was read in Paris in June, 1932. In October, 1935, he delivered his presidential address to the Rugby Engineering Society on "Engineering and Mathematics."

In the developments of turbo-alternators he was one of the pioneers of high-voltage generation, and as far back as 1922 he was consulted on the design of some 22 000-volt low-speed synchronous motors; the ideas he put forward at that time were afterwards developed further in connection with turbo-alternators generating at 33 000 volts, of which many are now in successful operation. As a result of his close co-operation with forge masters and others, he introduced into the con-

struction of alternator rotors alloy steels of a much higher grade than had previously been used. He was one of the pioneers of the use of non-magnetic steel for retaining rings, and was also the pioneer of the use of service exciters for turbo-alternators, in order to obtain quick-response excitation. For this purpose he originated a special design of exciter in which the service exciter was incorporated in the same frame as the main exciter.

By nature he was somewhat reserved; but he possessed a keen sense of humour and was very much respected by all members of his staff and others who came into personal contact with him. He was a member of the Newcomen Society and had for some years taken a keen interest in the proceedings of that Society. He was elected a Student of The Institution in 1900, an Associate Member in 1911, and a Member in 1927. P. H.

RENÉ THURY died at Geneva on the 23rd April, 1938, age 78. At the age of 14 he was apprenticed to the Société pour la Construction d'Instruments de Physique, a Geneva firm of scientific instrument makers, where he learned what was then known of the principles of electromagnetism. In 1875 he was sent by his firm to act as laboratory assistant first to Prof. Soret in connection with the spectroscopical research, and later to Pictet, who was then making his classical experiments on vapour pressure and liquefaction of gases. While working under Prof. Soret he conceived the idea of making a generator supply its own excitation current, a discovery which anticipated by 2 years Edison's first shunt-wound machine. In 1880 he spent several months in America as an assistant in Edison's laboratory, where he distinguished himself by showing that the Edison dynamos of that day could be improved by reducing the length of the poles and employing narrower air-gaps. During his stay in America he was asked to suggest a means of avoiding inductive interference on underground telephone cable. He constructed a cable consisting of pairs of conductors twisted together and enclosed in a lead sheath, which proved to be entirely immune from interference. Returning to Switzerland, he was engaged by his previous employers on the design and installation of Edison and Gramme dynamos, which were being manufactured by the firm under licence. Later he served for a short time in the works of Messrs. Bürgin and Alioth, and then in 1881 was placed in charge of the construction of electrical machines at the factory opened in that year by Messrs. de Meuron and Cuénod (later the Société Anonyme des Ateliers de Sécheron), with whom he remained for many years. He was also appointed chief engineer of the Compagnie de l'Industrie Électrique, and as such was one of the pioneers of electric traction, being responsible for the first electrically-driven rack railway installed in France. His best-known contribution to electrical engineering is, however, the constant-current d.c. series system of power transmission, which he successfully evolved in 1890 and which necessitated the solution of a number of intricate problems, such as that of sparkless commutation at high voltages and large currents, and the invention of regulating devices for maintaining constant current irrespective of the speed. He also invented the multipolar drum armature, as the outcome of a theoretical investigation which was fully supported by experiment. In later years he turned his attention to the construction of high-frequency alternators. He produced machines with an output of 1 000 kW at 30 000–40 000 cycles per sec., equipped with a speed regulator of his own design having an accuracy of 1 in 20 000. These alternators and regulators were installed in the principal French wireless-telegraph stations. He was made a Chevalier of the Legion of Honour in 1907, and in 1909 there was conferred upon him by the École Polytechnique Fédérale the honorary degree of doctor of applied science. He was elected an Honorary Member of The Institution in 1934. After retiring from the active service of his company he devoted himself to experiments dealing with regulating devices, high-frequency furnaces, and other problems. C. G.

LIEUT.-COLONEL OSWALD THOMAS O'K. WEBBER died on the 25th August, 1938, at the age of 68. He joined the 2nd Division Telegraph Battalion, Royal Engineers, in 1898, and was appointed assistant to the sub-division officer of the Southern District, Post Office Engineering Department, with headquarters at Exeter. At the outbreak of the Boer War he went to South Africa. He was taken prisoner early in the campaign and was not released until the advance to Pretoria was completed. His experiences as a prisoner of war appeared to have affected his health, but this did not prevent the active and energetic performance of his duties which he resumed in the sub-division office at Exeter in 1903. In 1909 he accompanied the "K" Telegraph Co. to Ireland when it took over the duties of the Post Office Engineering Department in the South Irish District. In 1910 he resigned his commission in the Army, as he was medically unfit for foreign service, and in the same year he was appointed assistant superintending engineer in the Post Office. He rejoined the Army in August, 1914, and took command of the cadre "K" Telegraph Co. which remained in Ireland throughout the Great War. He resigned his appointments, both military and civil, in 1922. He was elected an Associate of The Institution in 1894, an Associate Member in 1899, and a Member in 1907. A. G. L.

SAMUEL WHIPP, founder and vice-chairman of Messrs. Whipp and Bourne, died on the 15th May, 1938, at the age of 62. He was educated at Wesley College, Sheffield, and at the Rochdale Collegiate School, and attended evening classes at the Manchester Technical School. From 1893 to 1898 he was an apprentice with Messrs. Woodhouse and Rawson, of Manchester, and with their successor, Mr. Bertram Thomas. At the conclusion of his apprenticeship he remained with the firm, first as a draughtsman and later as chief assistant to Mr. Thomas, until 1903, when he founded the business of Messrs. Whipp and Bourne, of Castleton, Manchester. In collaboration with his brother, Mr. Frank Whipp, he turned his attention to the design of switchgear for use on naval ships, a field in which he achieved outstanding success. At the time of his death he was vice-chairman of the company. He was elected a Member of The Institution in 1918.

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The photograph which is by the courtesy of Metropolitan-Vickers Electrical Co. Ltd., shows a general view of metalclad switchgear with M.V.C. aluminium alloy oil filled bushing chambers at the Battersea Power Station.

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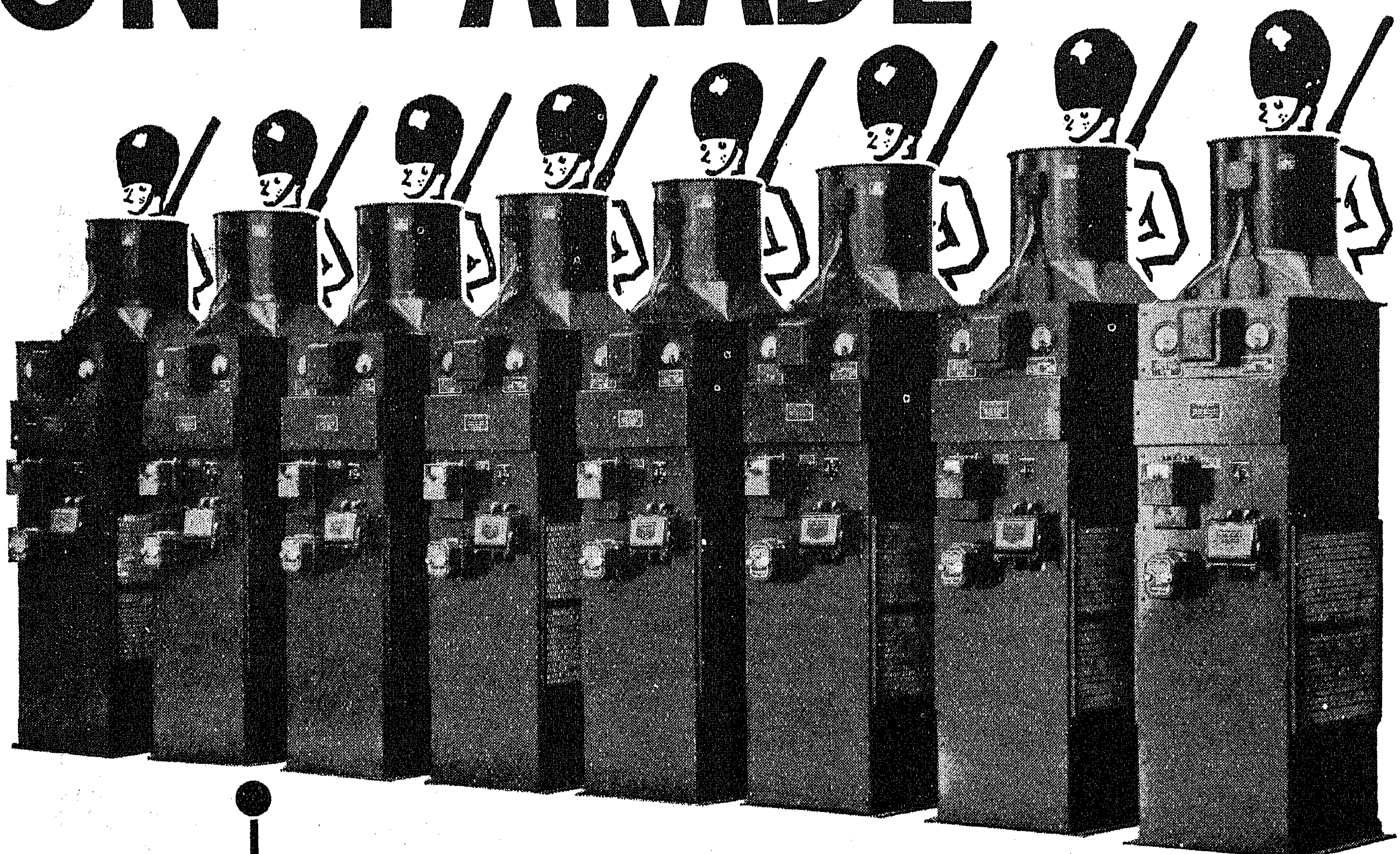
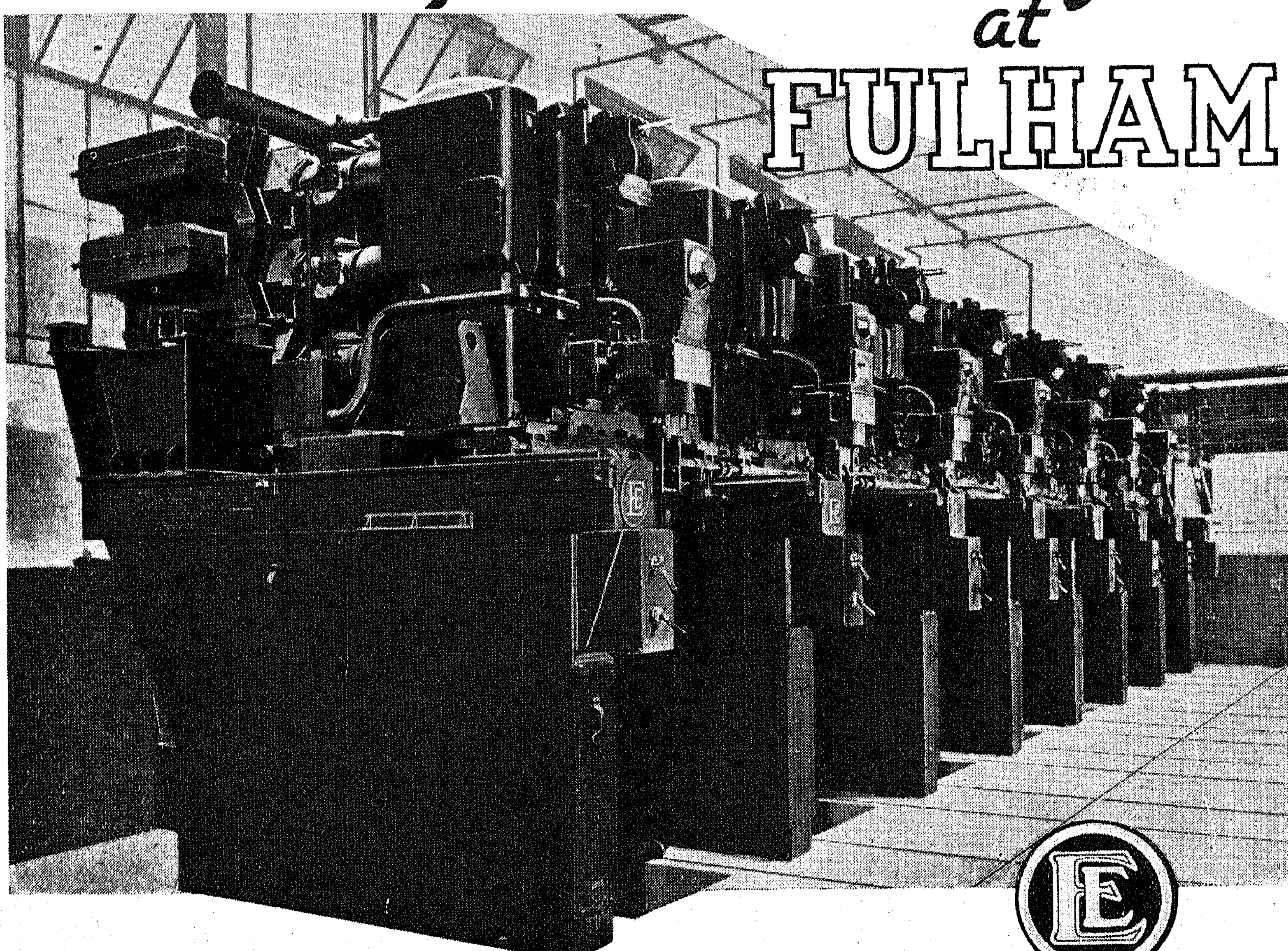


'ENGLISH ELECTRIC'
'De-ion Grid' Switchgear at FULHAM



The illustration shows part of a seventeen-panel 750 MVA. metalclad, drawout, duplicate busbar, electrically-operated switchboard, supplied to the Metropolitan Borough of Fulham. The circuit-breakers are fitted with De-ion Grid arc control devices which years of service and short-circuit testing have proved are the most efficient means of circuit interruption under all conditions of severity. These and the many noteworthy features of design make for reliability and trouble-free operation and reduce maintenance attention to a minimum.

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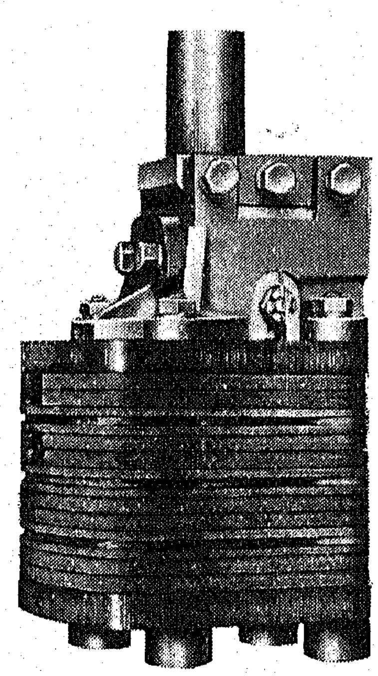

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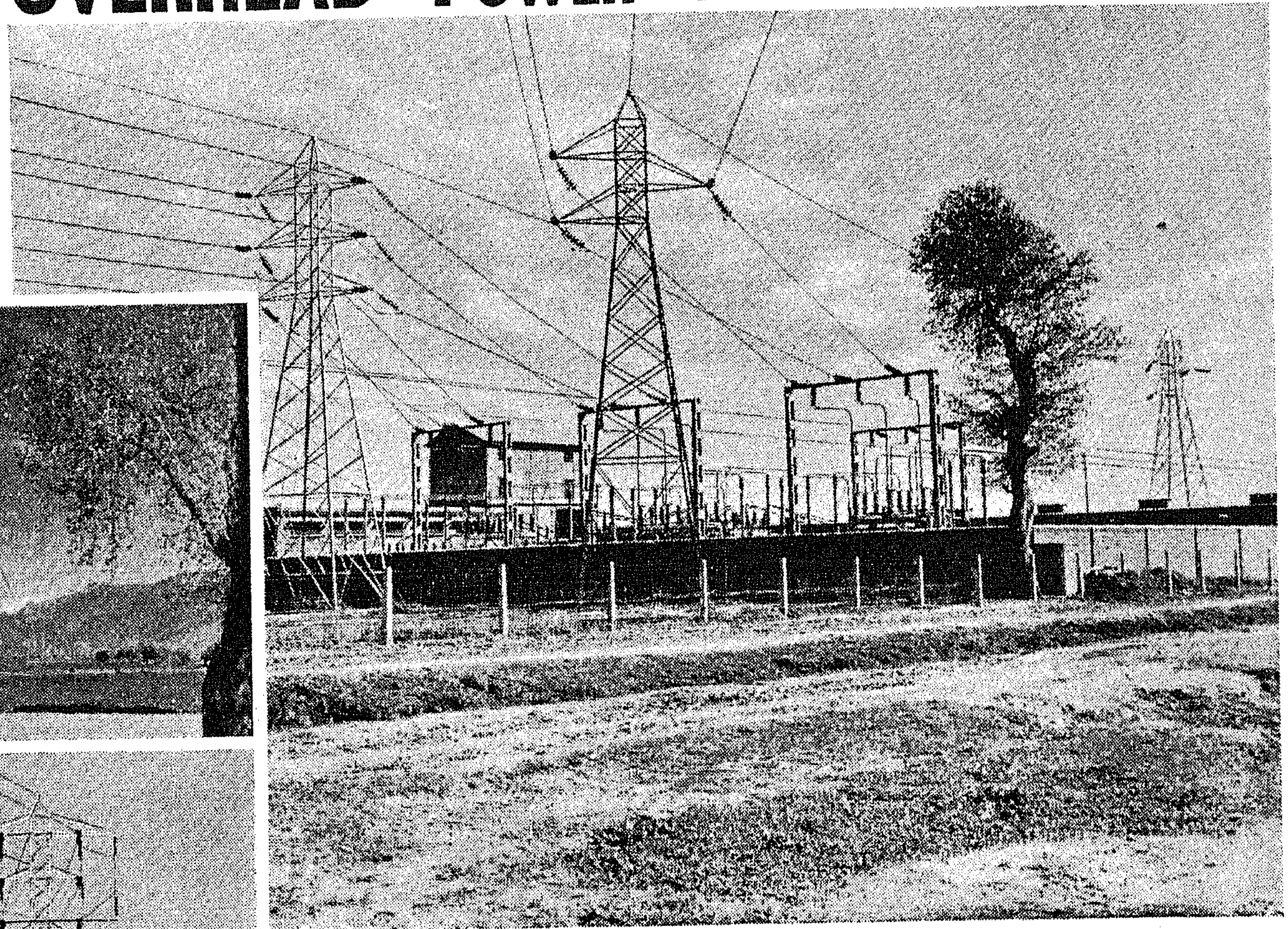
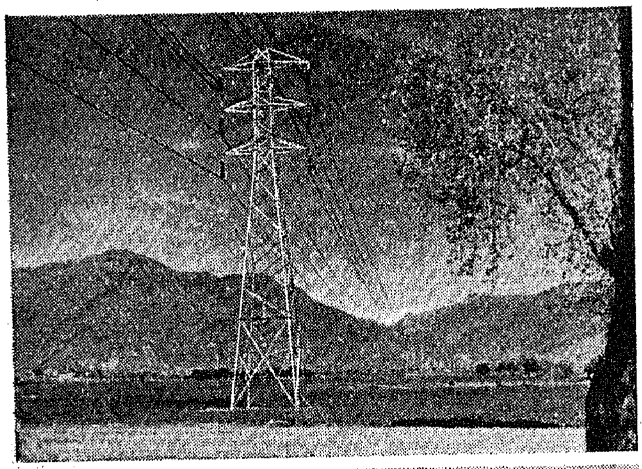
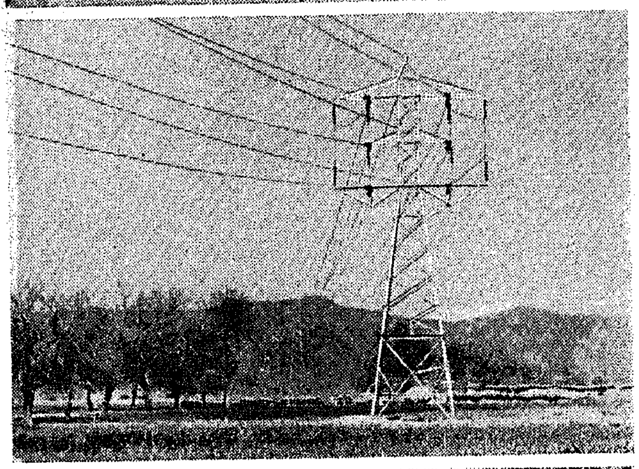
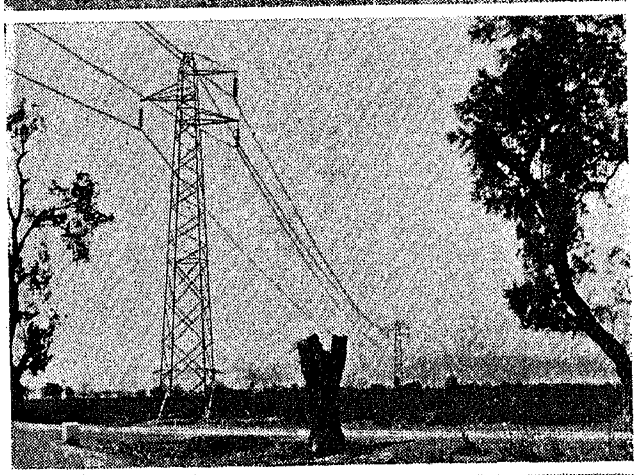
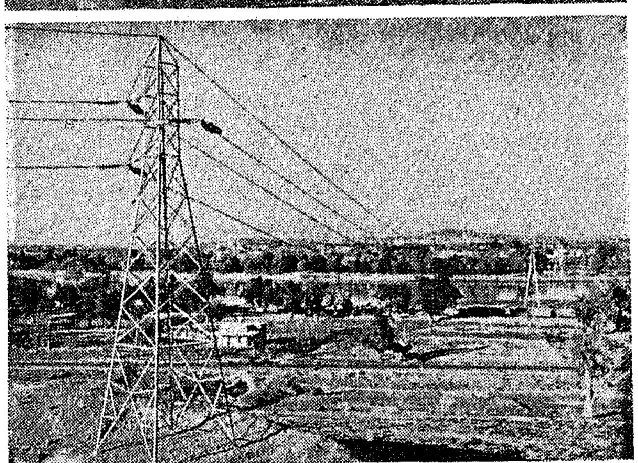




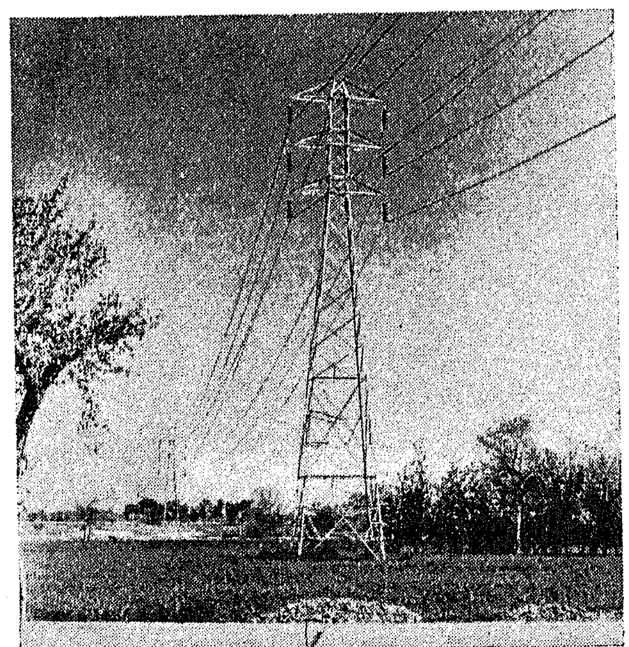






..on the NORTH WEST FRONTIER

The illustrations show different types of construction used for the 66 kV. lines of the Malakand Hydro Electric Scheme recently carried out by the **B. I.** The contract comprised 104 miles of single and double circuit overhead power transmission lines in the Malakand district of the North West Frontier Province of India. The large picture is of terminal towers at Mardan sub-station, and other views are of double-circuit straight line towers, double-circuit transposition tower, single-circuit straight line towers, and single-circuit railway, road and river crossing.



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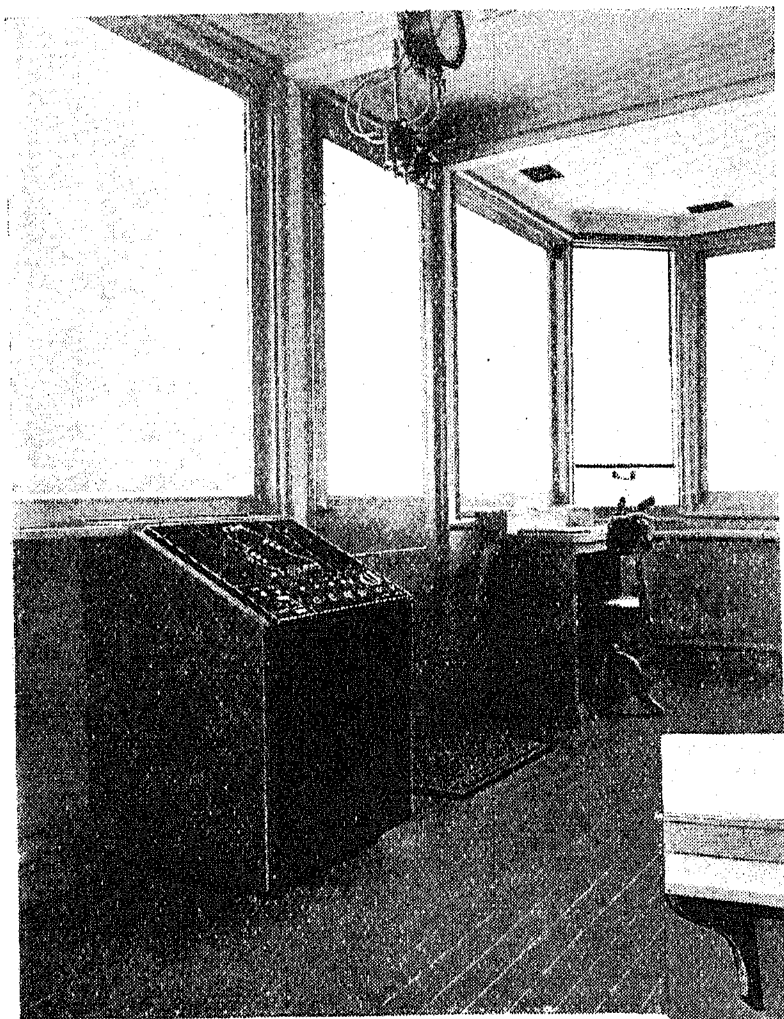
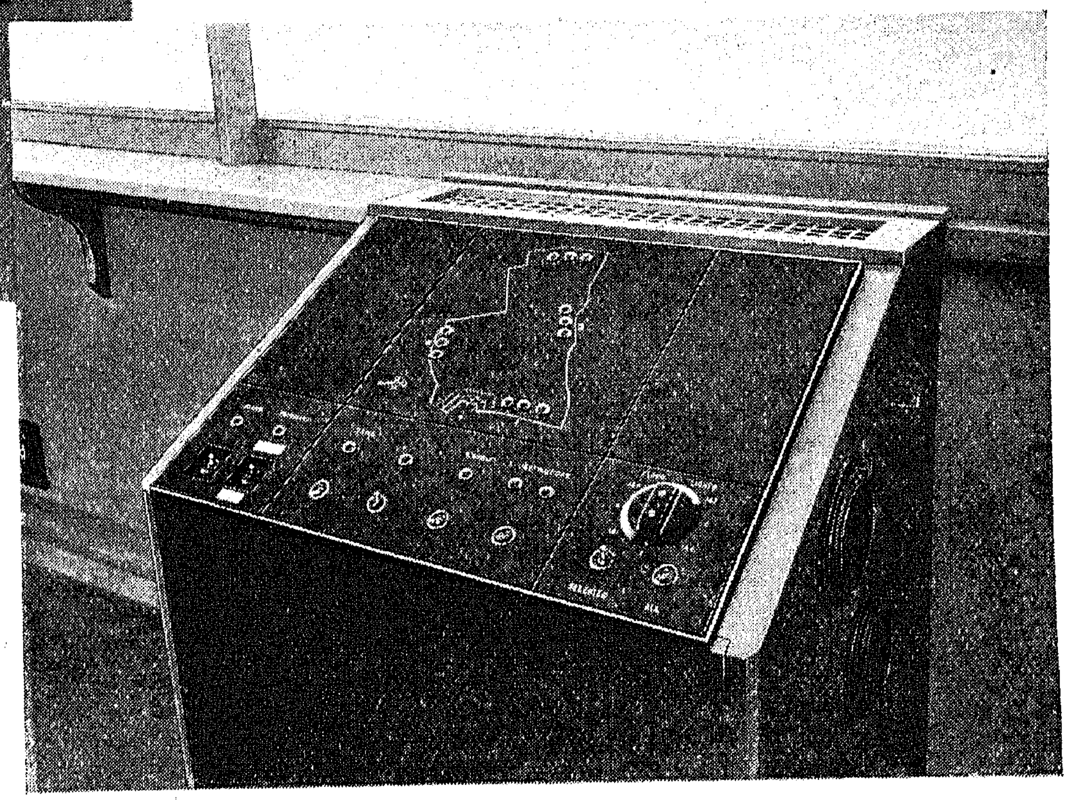


Landing a plane at night is a dangerous and hazardous task, and one for which the pilot requires the full co-operation of the ground staff. To give him this co-operation it is essential that the control engineer should have at his finger tips the means to switch on the boundary and obstruction lights, to start up emergency generators and to sound the fire, ambulance or crash alarms. The control engineer at Jersey Airport, using a control panel of "Strowger" manufacture, can do any of these things merely at the touch of a switch.



The panel is fitted with pilot lamps which confirm that the various operations have been successfully carried out and show at a glance, at any time, the conditions obtaining on the field electrical equipment. Manufactured by the Automatic Telephone & Electric Co., Ltd., to specifications prepared by Messrs. Norman & Dawbarn, Airport Consulting Engineers, London.

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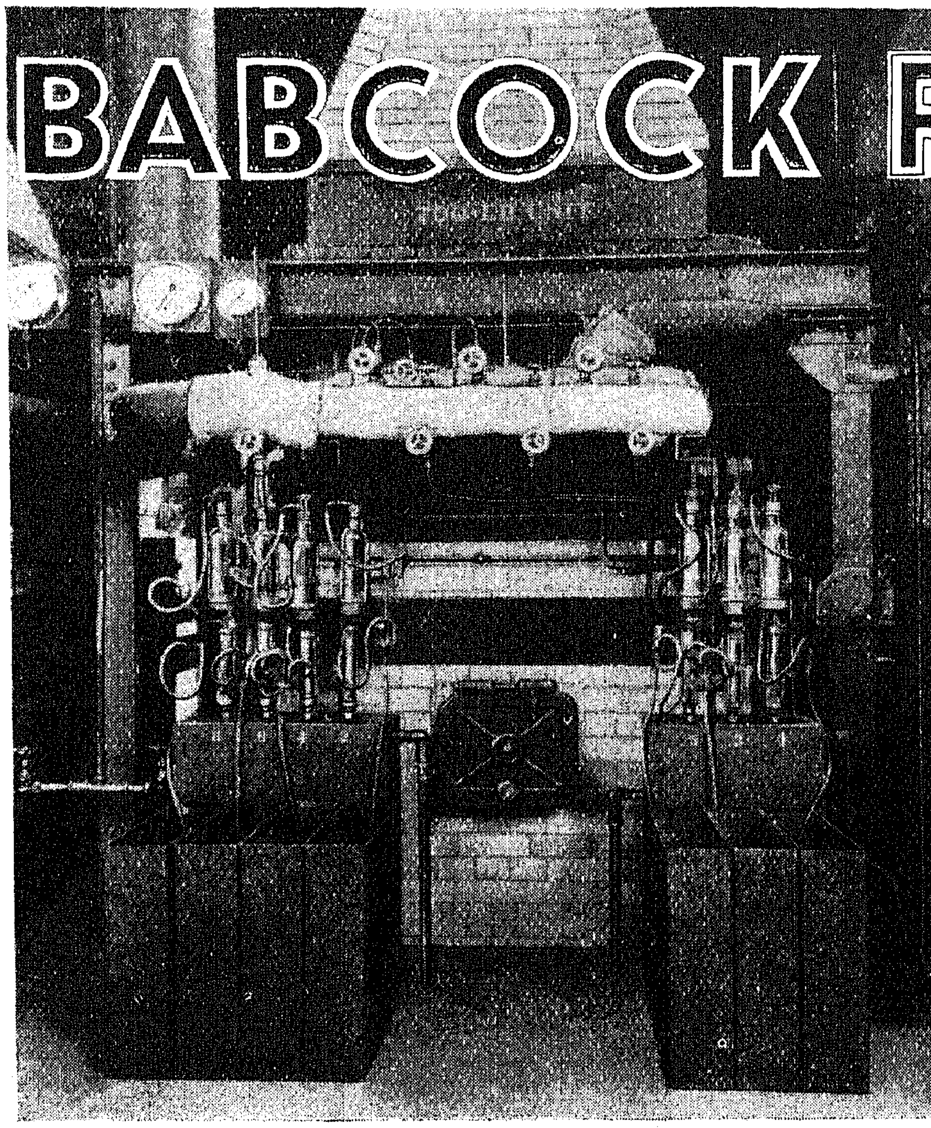

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The top illustration shows one of two special superheaters in which series of tubes of different materials are subjected to high steam temperatures to determine their resistance and behaviour under these conditions.

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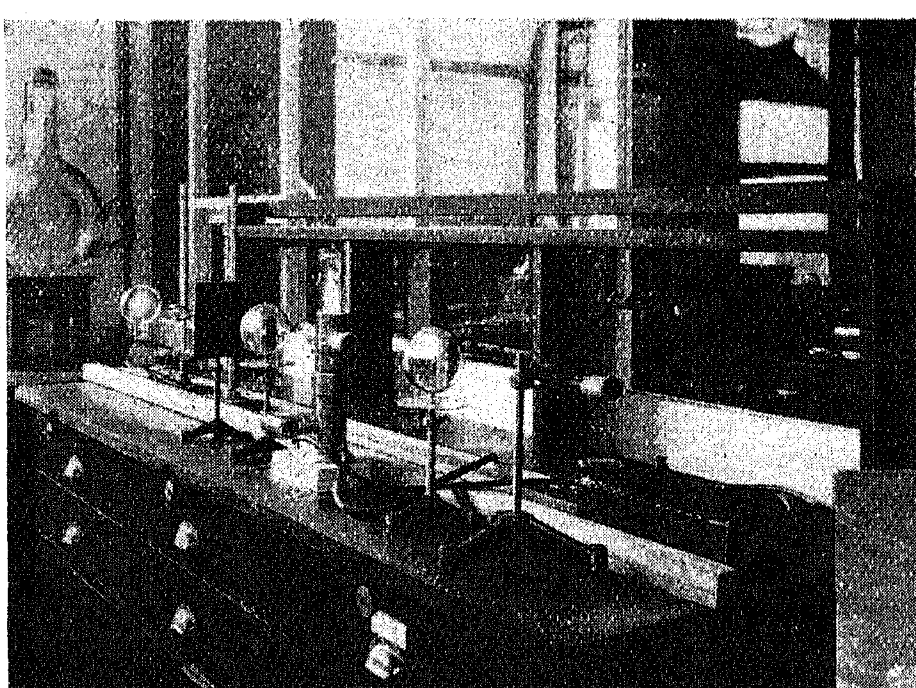
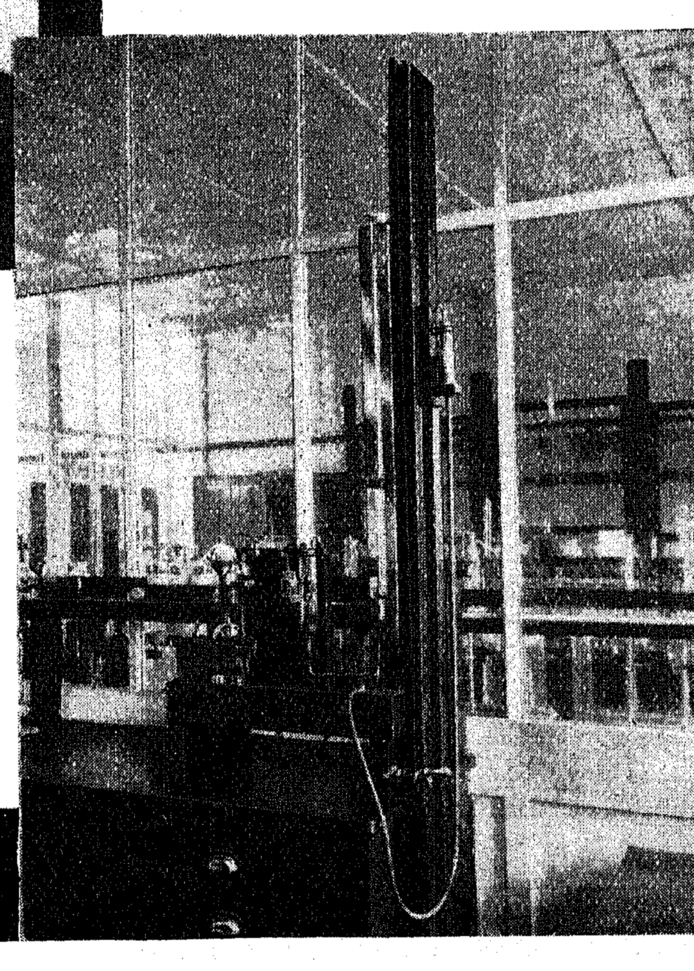
The accurate determination of furnace gas temperatures where the conditions are not black-body is a difficult problem, necessitating the use of special apparatus. The centre illustration shows an adaptation of the Sodium Line Reversal Method which has been used for the determination of temperatures in internal combustion engines and is now, for the first time, being applied to boiler practice.





The lower illustration shows a Micro Gas Analysis Apparatus which enables analyses of very small quantities of gas to be carried out with speed and accuracy. The special apparatus used for the measurement of the rate of evolution of gas from condensed steam and for collecting gas samples is shown in front of the superheater in the illustration. This investigation is yet another example of the importance Babcock & Wilcox Ltd., attach to the results obtainable from practical research work.

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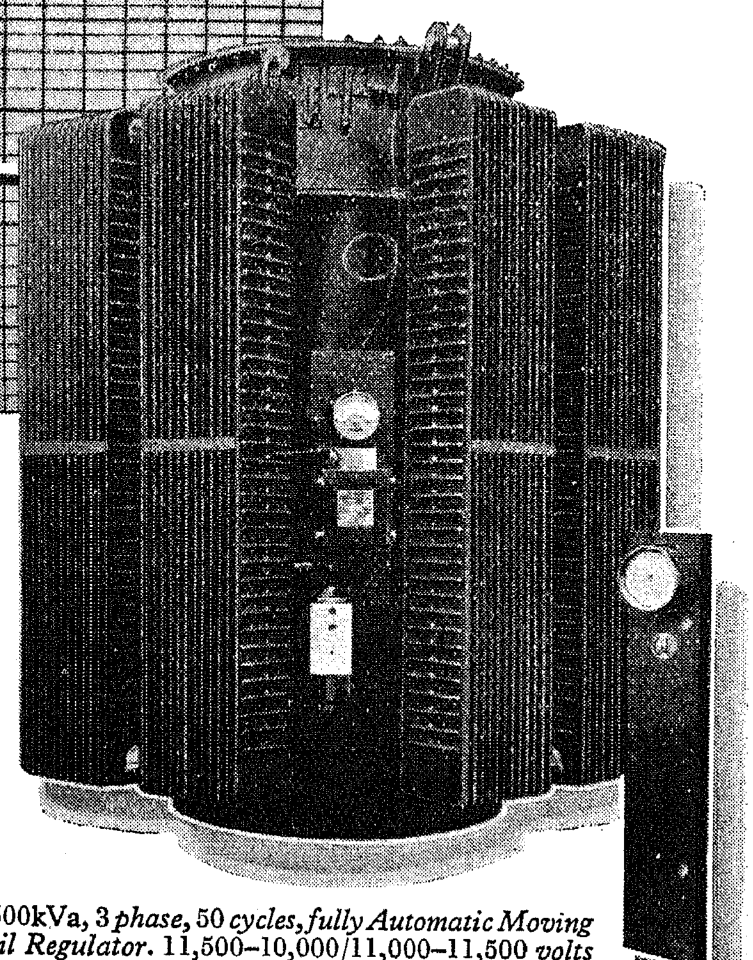

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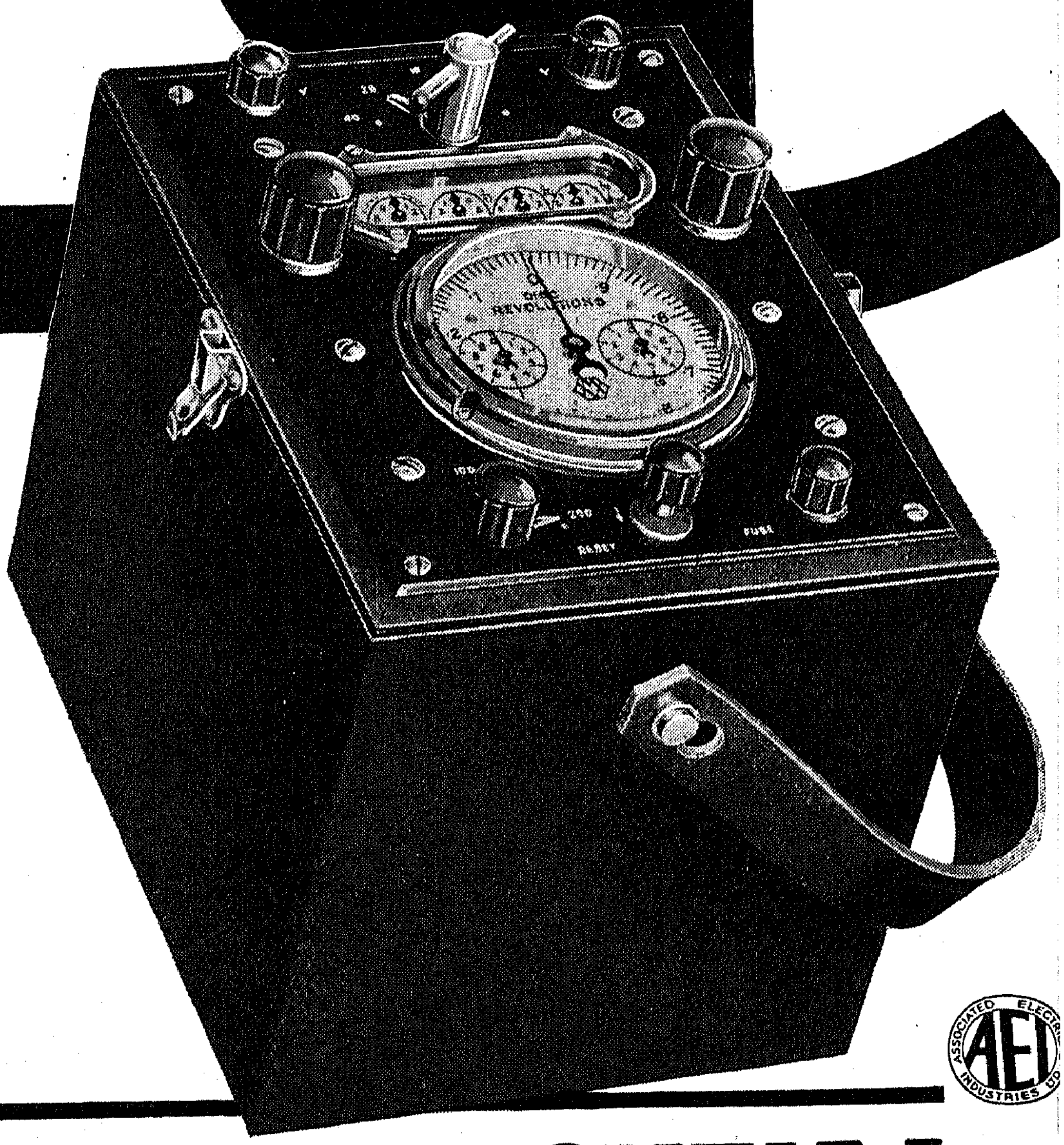

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